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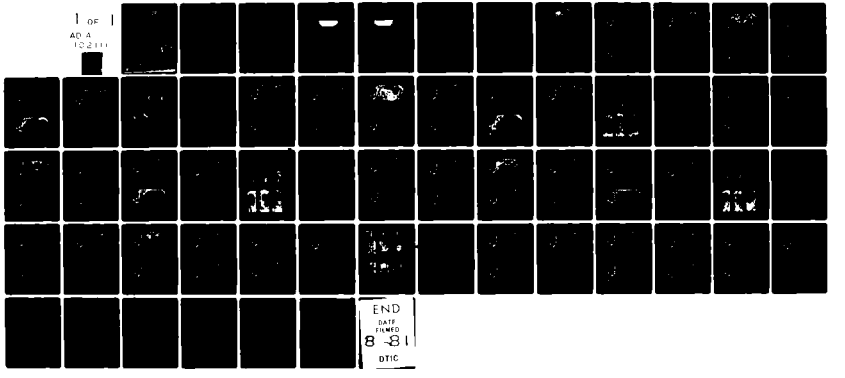

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Since 1976, three reports on oceanographic and meteorological conditions in the North Pacific have been produced by the NORPAX Data Program covering the period from June, 1976 through November, 1977. This is the fourth in the series, and covers the period from December, 1977 through May, 1978. This issue contains: contour maps of monthly meaned Fleet Numerical Oceanographic Central (FNOC) air temperature, sea temperature, wind speed, wind direction, surface vapor pressur, and 700 mb height; NORPAX...

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CURL OF WIND STRESS CORRIGENDUM TO ADS REPORT NUMBER 4

Curl of wind stress maps in the ADS 4 report are incorrect. These are the corrected maps. The discussion in the Appendix to ADS Report number 4 is correct and pertains to this corrigendum.

Corrected maps inserted in report.
6 Aug 81

1

# NORPAX
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## INTRODUCTION

Since 1976, three reports on oceanographic and meteorological conditions in the North Pacific have been produced by the NORPAX Data Program covering the period from June, 1976 through November, 1977. This is the fourth in the series, and covers the period from December, 1977 through May, 1978. This issue contains: contour maps of monthly meaned Fleet Numerical Oceanographic Central (FNOC) air temperature, sea temperature, wind speed, wind direction, surface vapor pressure, and 700 mb height; NORPAX Data Management calculated wind stress, wind stress curl, wind shear velocity cubed, sensible heat flux, latent heat flux; objectively analyzed TRANSPAC temperatures at discrete depths from White and Bernstein (SIO); monthly ADS buoy drifter displacement vectors from McNally (SIO).

## CONTOUR MAPS

Contour maps of FNOC (Fleet Numerical Oceanographic Central) fields and calculated flux fields are in Figures 2.1-2.11, 3.1-3.11, 4.1-4.11, 5.1-5.11, 6.1-6.11, and 7.1-7.11. TRANSPAC contour maps are in Figures 2.12, 3.12, 4.12, 5.12, 6.12, and 7.12.

The analysis of FNOC fields and NORPAX calculated flux fields are explained in the Appendix to this issue.

XBT's have been regularly dropped from ships of opportunity in the Pacific since 1974. Recovered temperature profile data have been analyzed at Scripps by Bernstein and White and temperature residuals from their anomalies were contoured for 0, 60, 120, 200, 300 and 400 meter depths, by month.

## FREE DRIFTER BUOY DISPLACEMENT VECTORS

Buoy displacement vectors were plotted in Figures 2.13, 3.13, 4.13, 5.13, 6.13, and 7.13. The buoys were drogued at 30 meters.

## ACKNOWLEDGEMENTS

First, to Anna Moore for her work organizing the figures, xeroxing them using the painstaking Standard Xerox process, we wish to give thanks. Also, to Ted Walker for producing the plots of subsurface temperature fields.

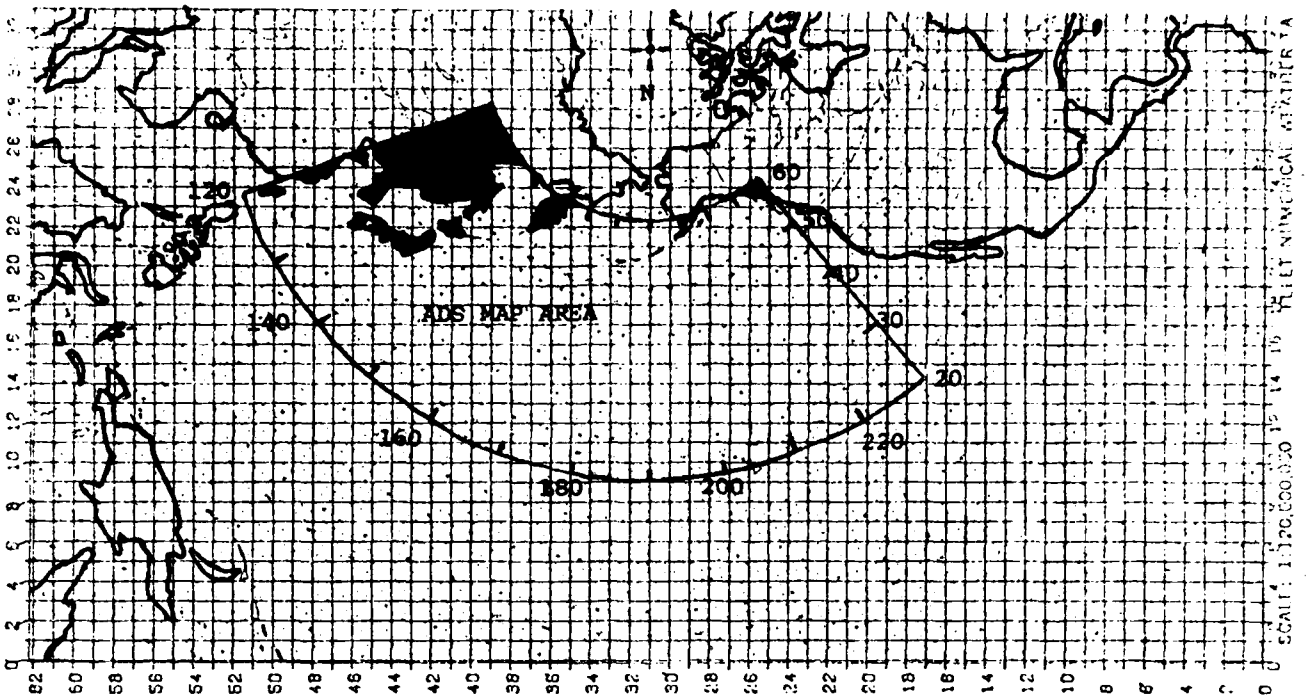



FIGURE 1. 33 x 63 field geographic coverage. The area of the ADS contour maps is as indicated. This map is a polar projection of the northern hemisphere.

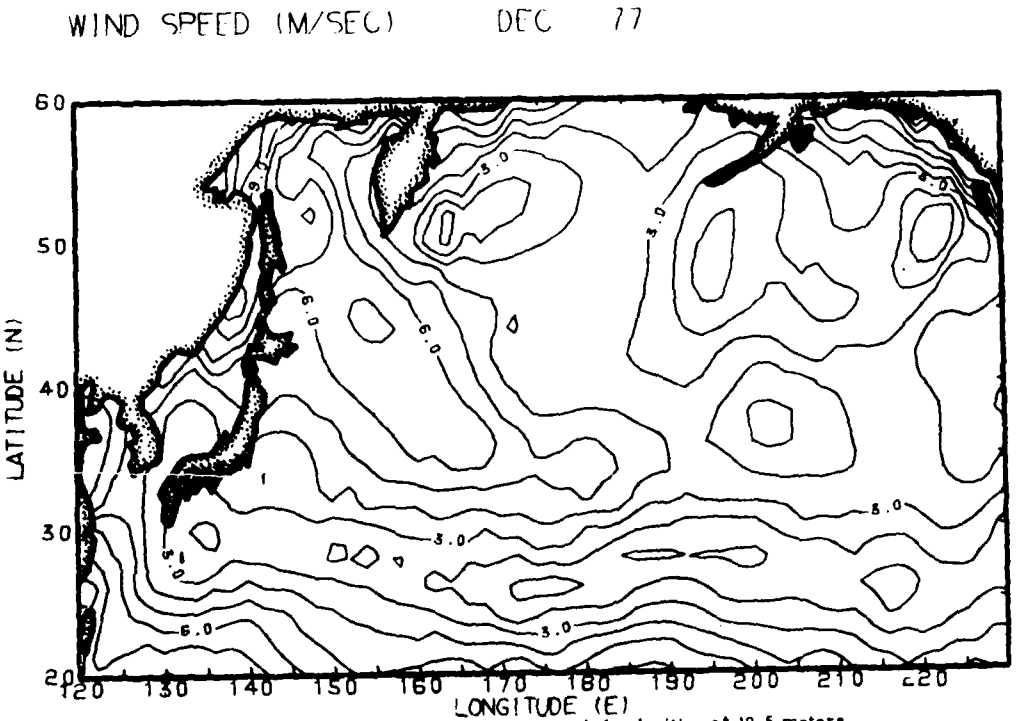



FIGURE 2.1 Absolute value of monthly mean vector wind velocities at 19.5 meters. Contour intervals are 1 m/sec.

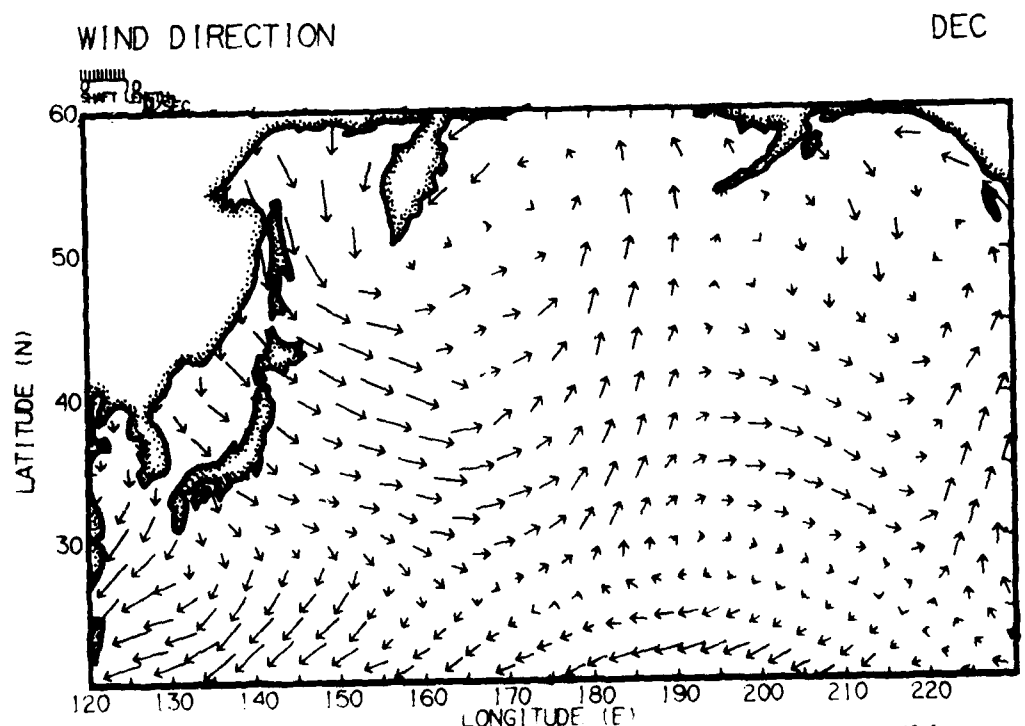



FIGURE 2.2 Direction arrows representing directions of monthly mean wind vectors at 19.5 meters. Length of arrow shaft indicates wind speed in m/sec. (See scale above figure).

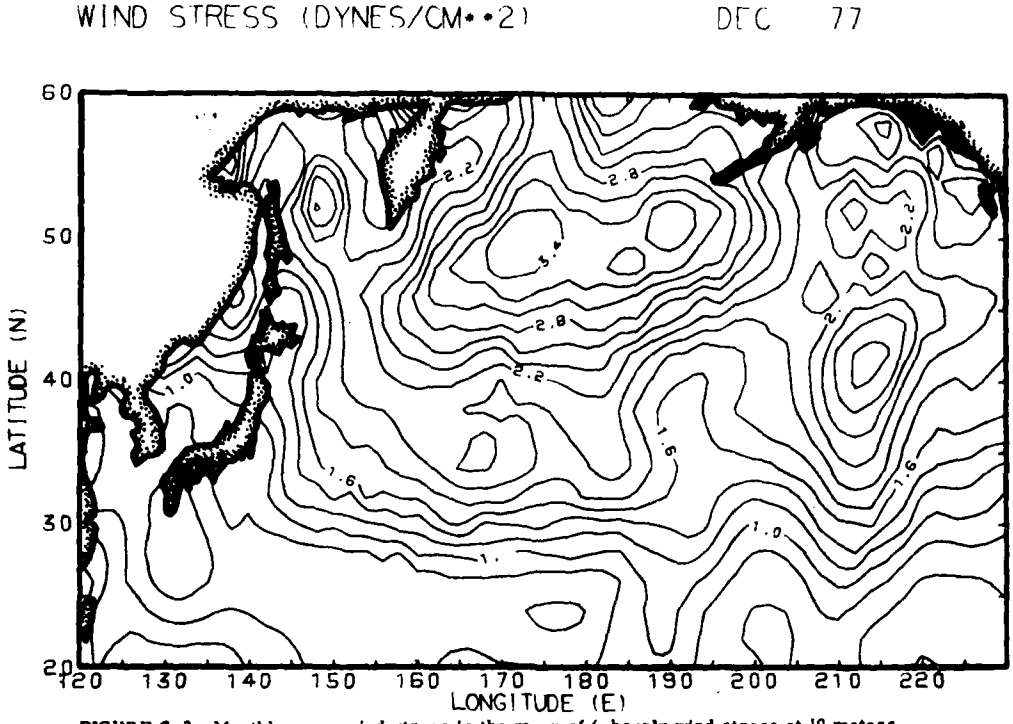



**FIGURE 2.3** Monthly mean wind stress is the mean of 6-hourly wind stress at 10 meters calculated from FNWC wind data. Contour intervals are 0.2 dynes/cm$^2$.

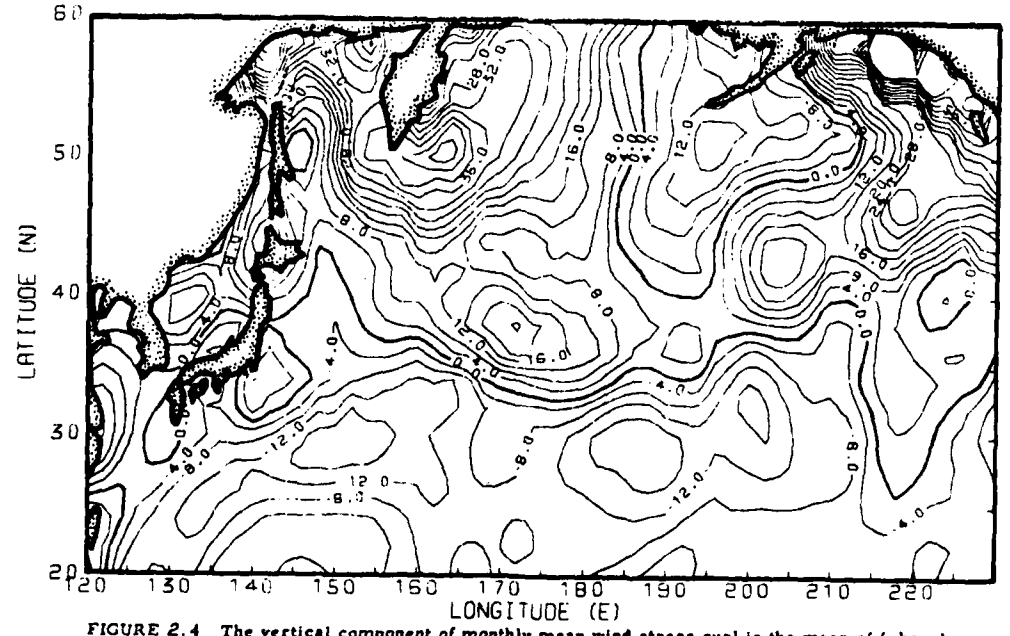



*FIGURE 2.4* The vertical component of monthly mean wind stress curl is the mean of 6-hourly wind stress curl approximated by finite-differences from 6-hourly wind stresses at 10 meters. Isolines of zero curl are plotted heavily, and contour intervals are $4.0 \times 10^{-9}$ dynes/cm$^3$.

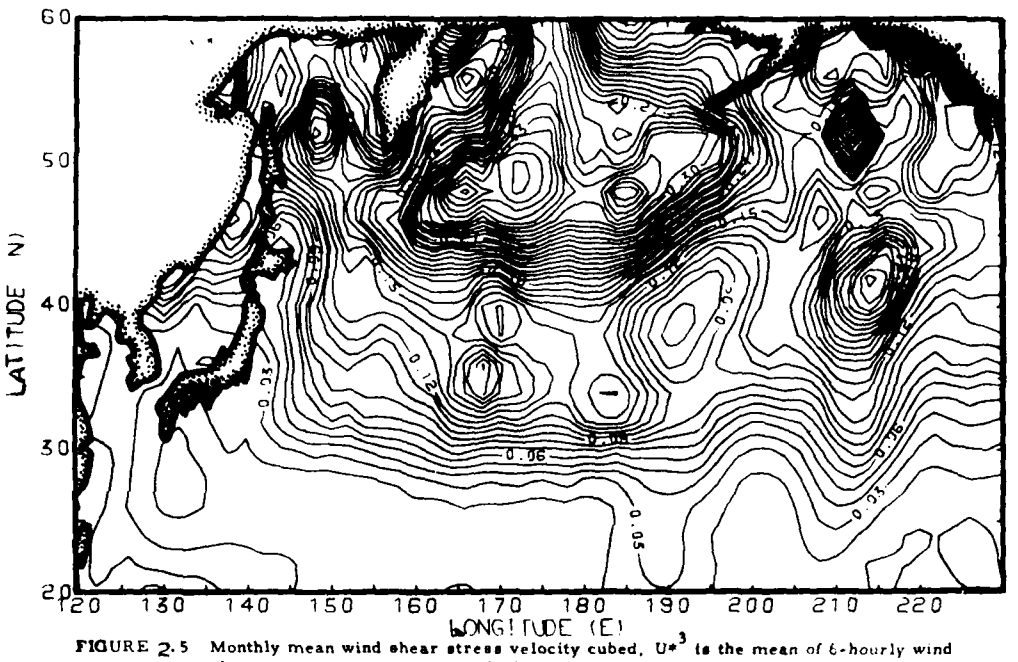
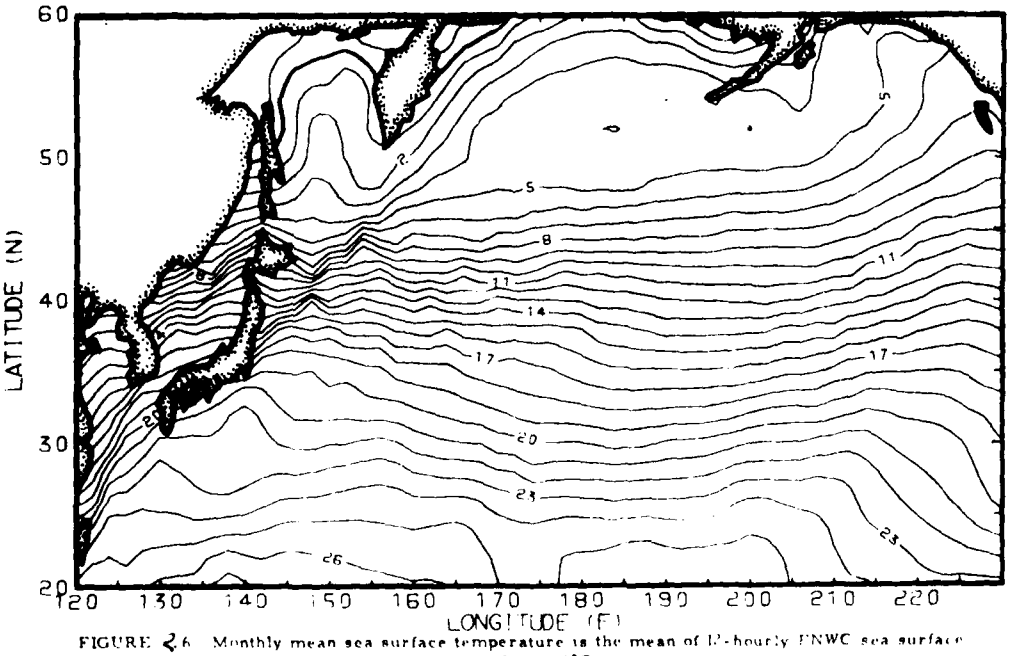



FIGURE 2.5 Monthly mean wind shear stress velocity cubed, $U^{*3}$ is the mean of 6-hourly wind shear stress velocity cubed calculated from wind speed at 10 meters. Contour intervals are 0.02 $(m/sec)^3$.

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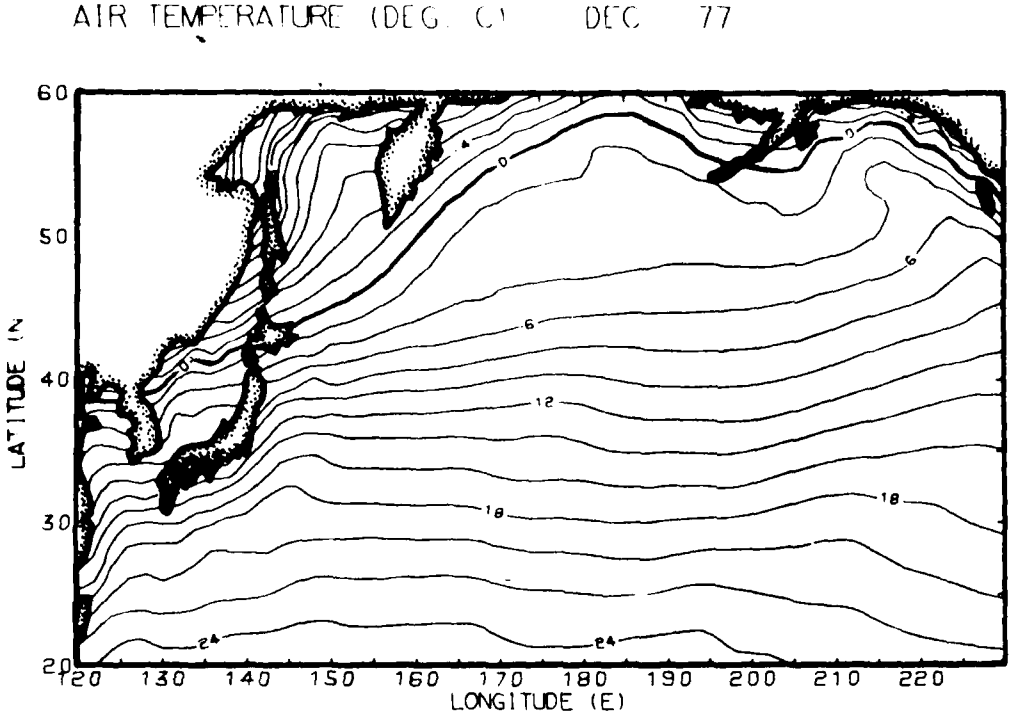



FIGURE 2.7 Monthly mean air temperature is the mean of 12-hourly FNWC air temperature. Contour intervals are 2°C.

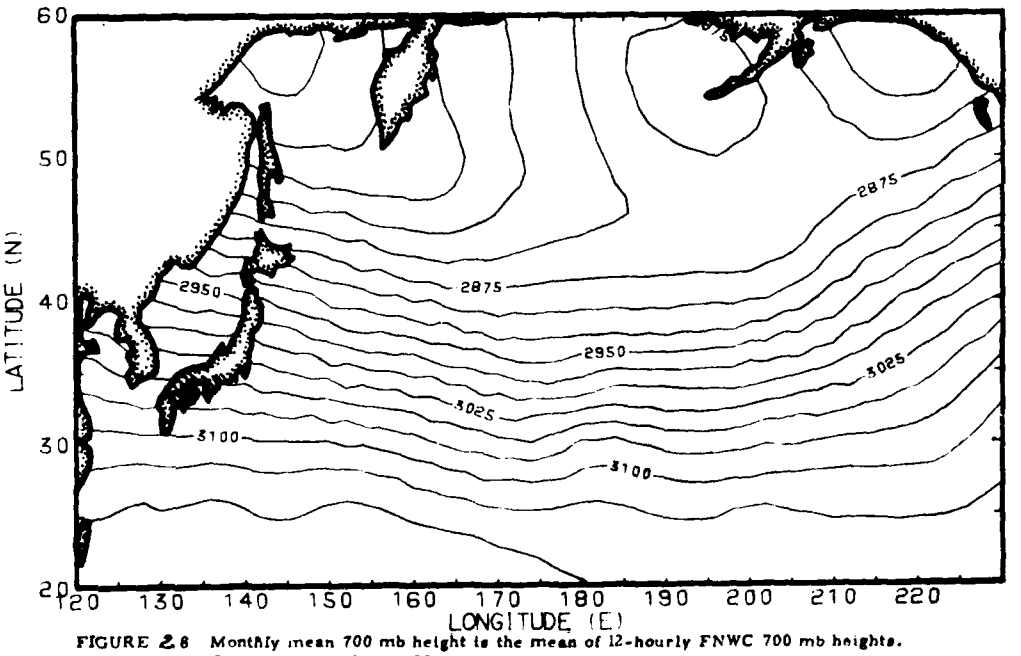
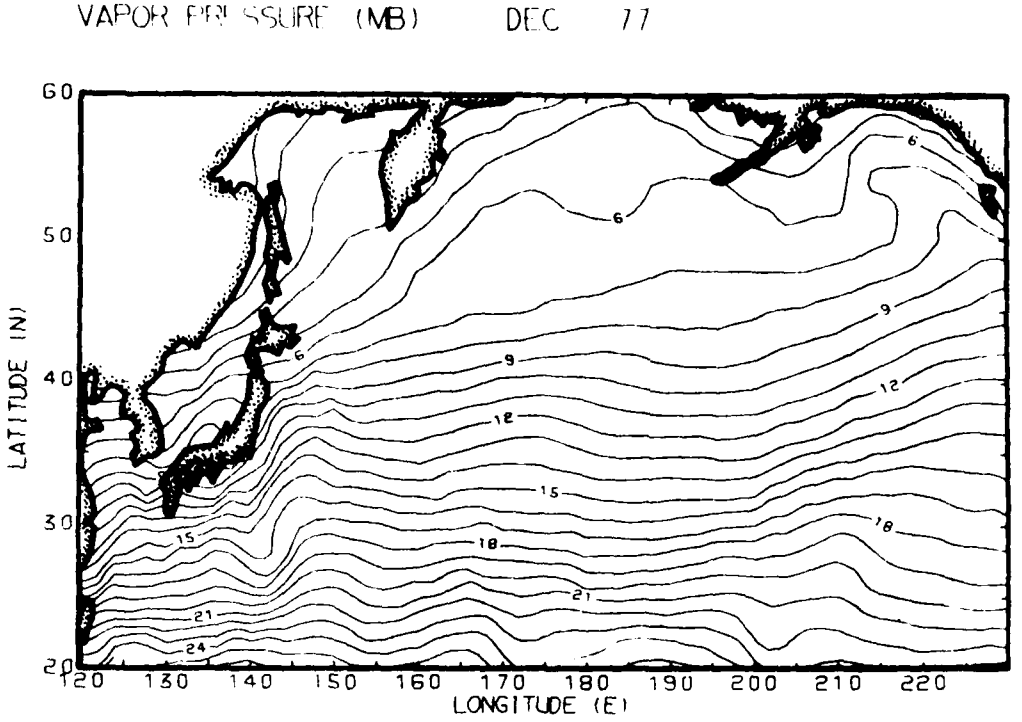



FIGURE 2.8 Monthly mean 700 mb height is the mean of 12-hourly FNWC 700 mb heights. Contour intervals are 25 meters.

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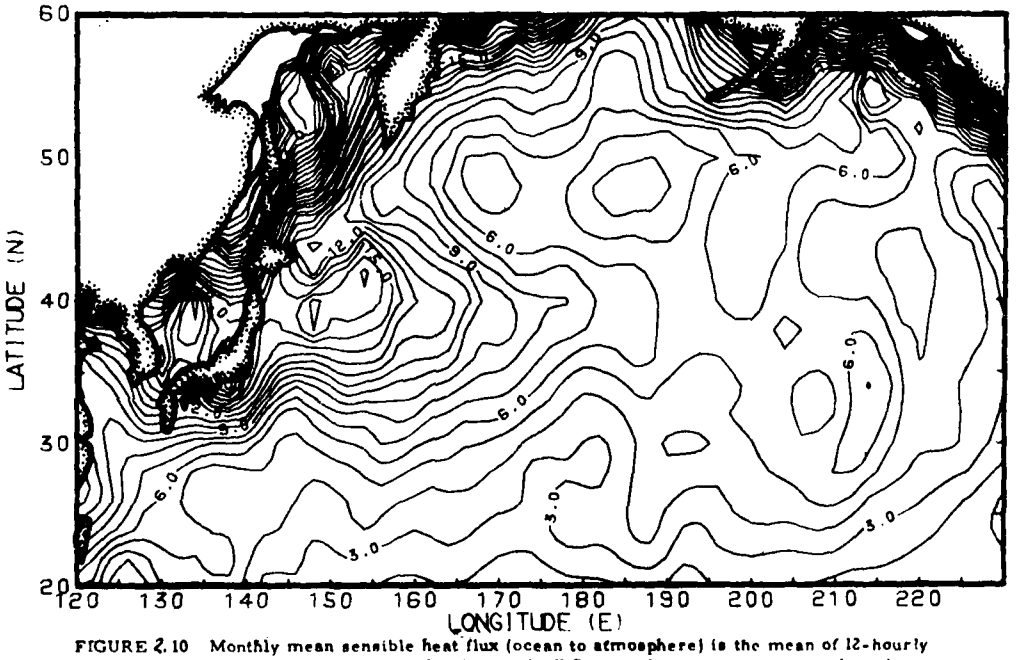
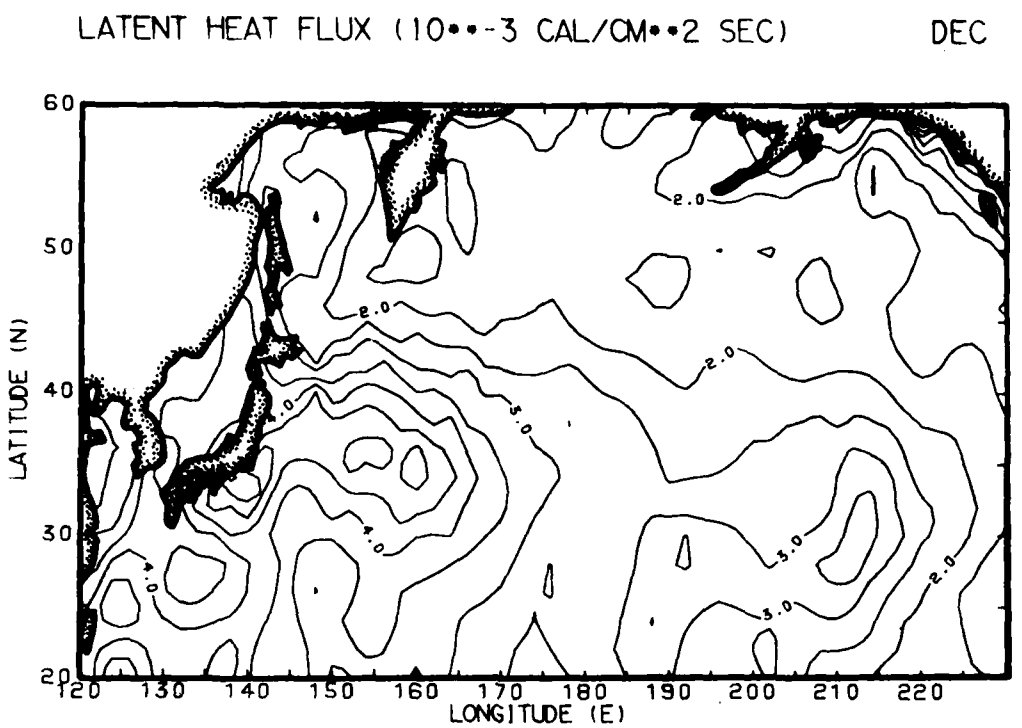



FIGURE 2.10 Monthly mean sensible heat flux (ocean to atmosphere) is the mean of 12-hourly sensible heat flux calculated from FNWC air and sea temperature and wind using a bulk formula. Isolines of zero heat flux are plotted heavily, and contour intervals are $1.0 \times 10^{-4}$ cal/cm$^2$ sec.

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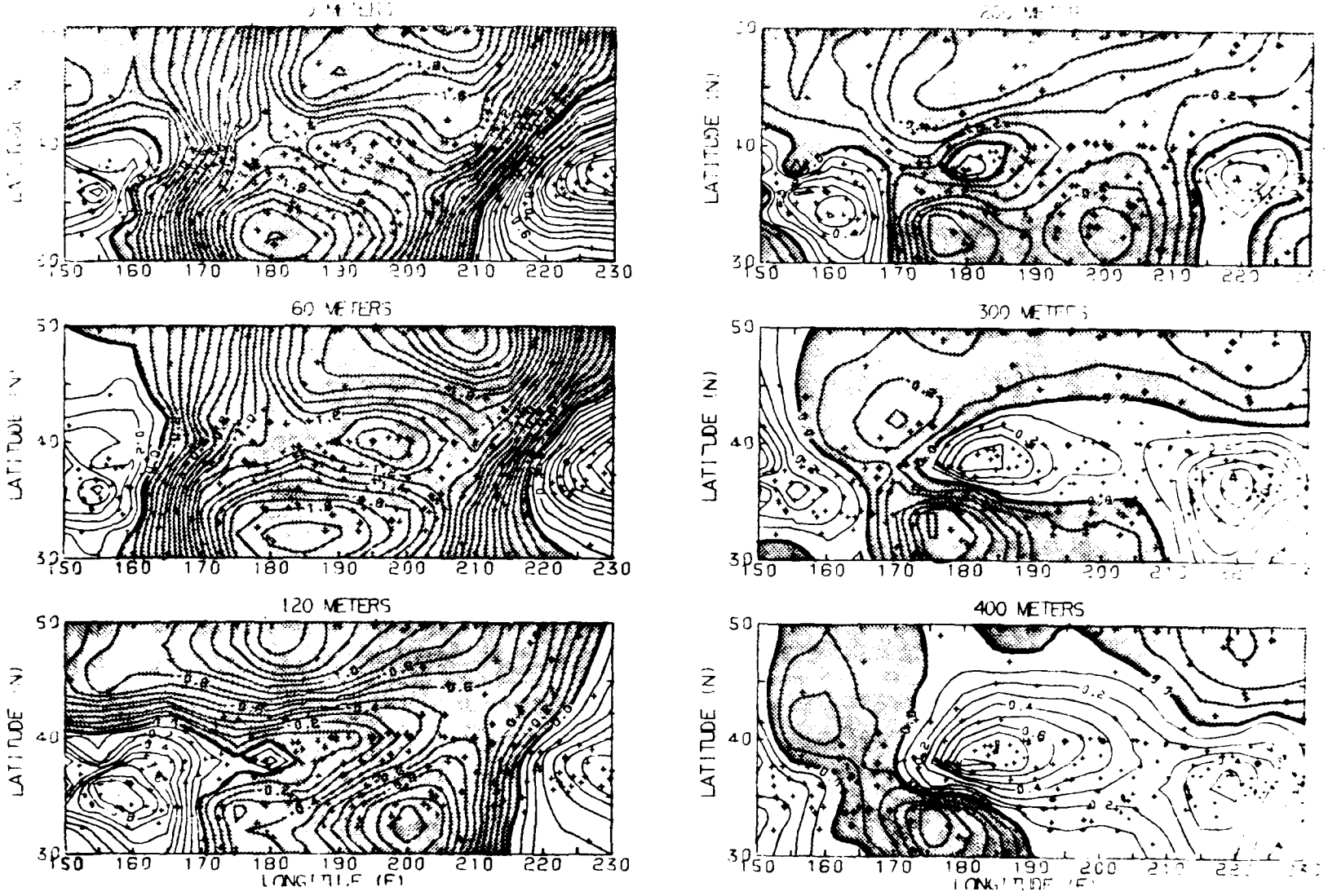


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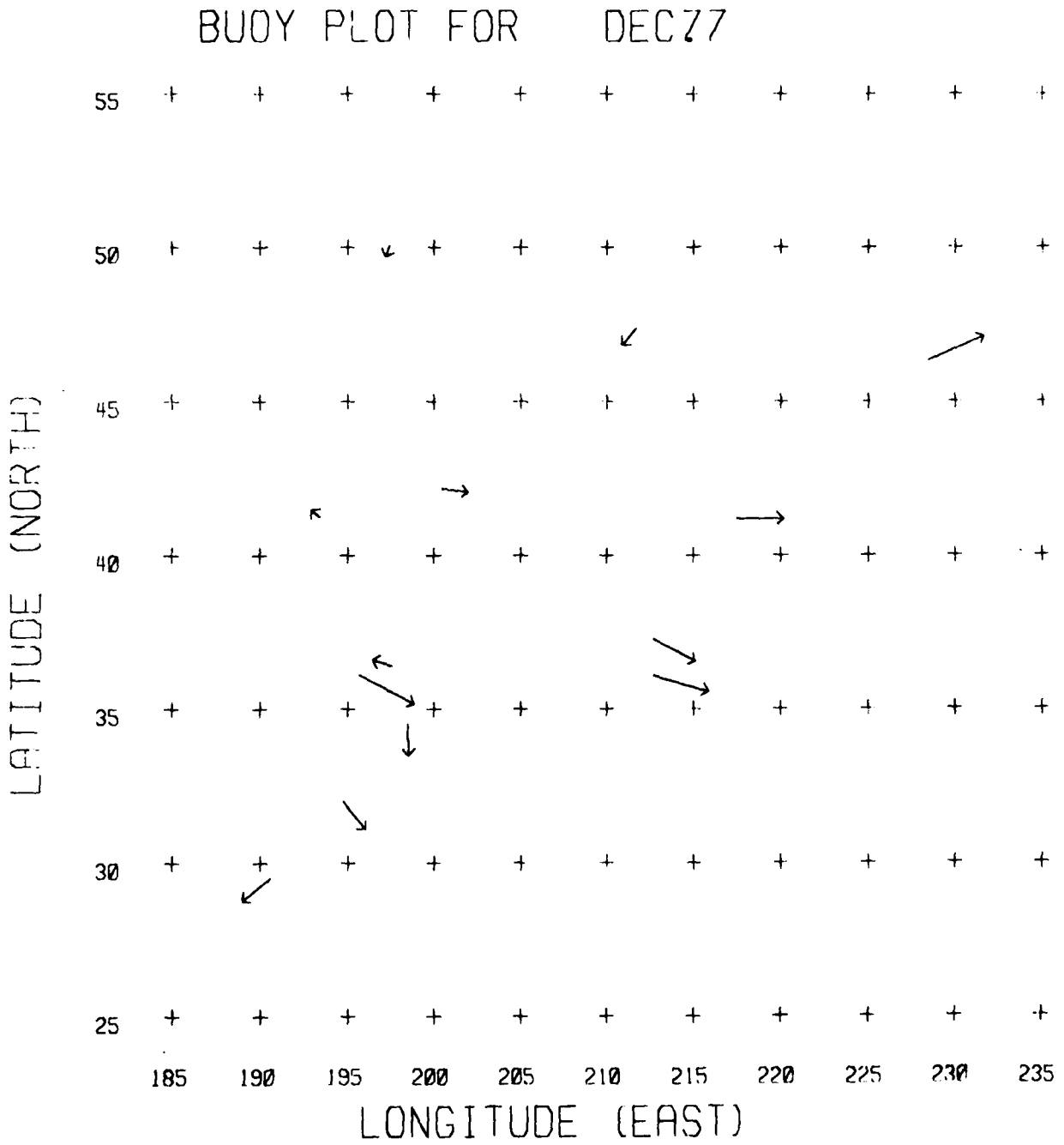


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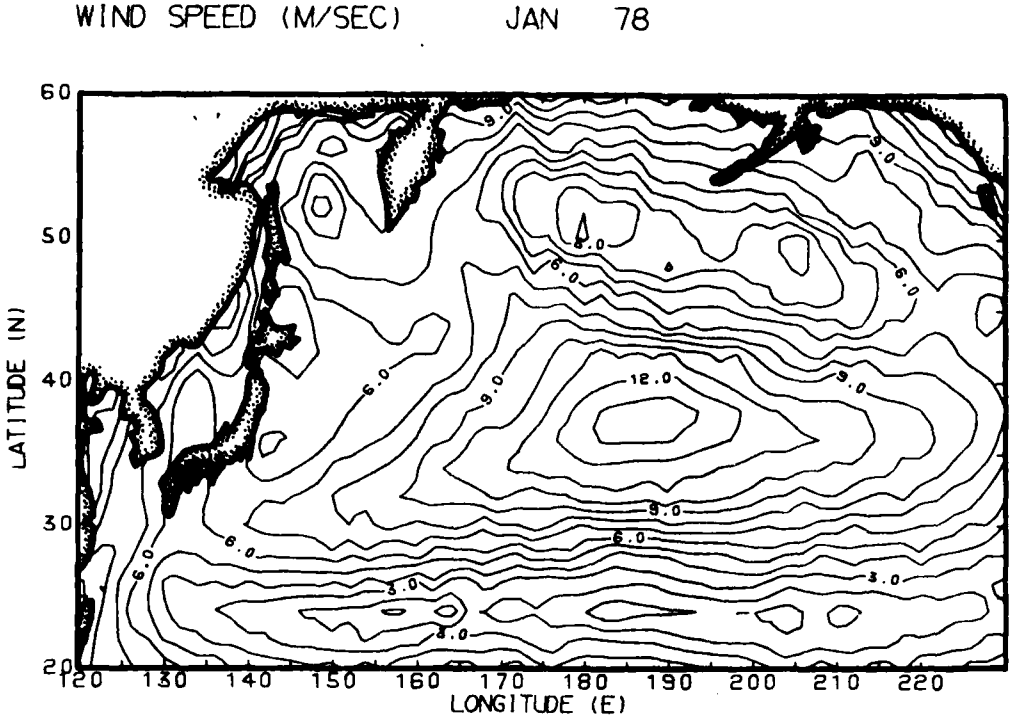


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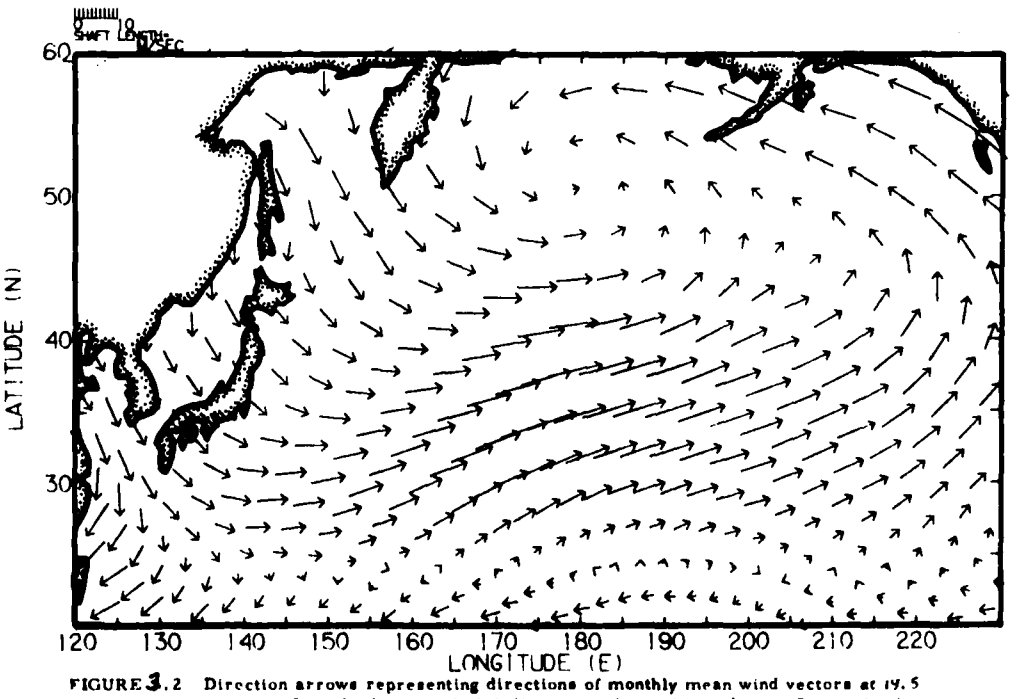


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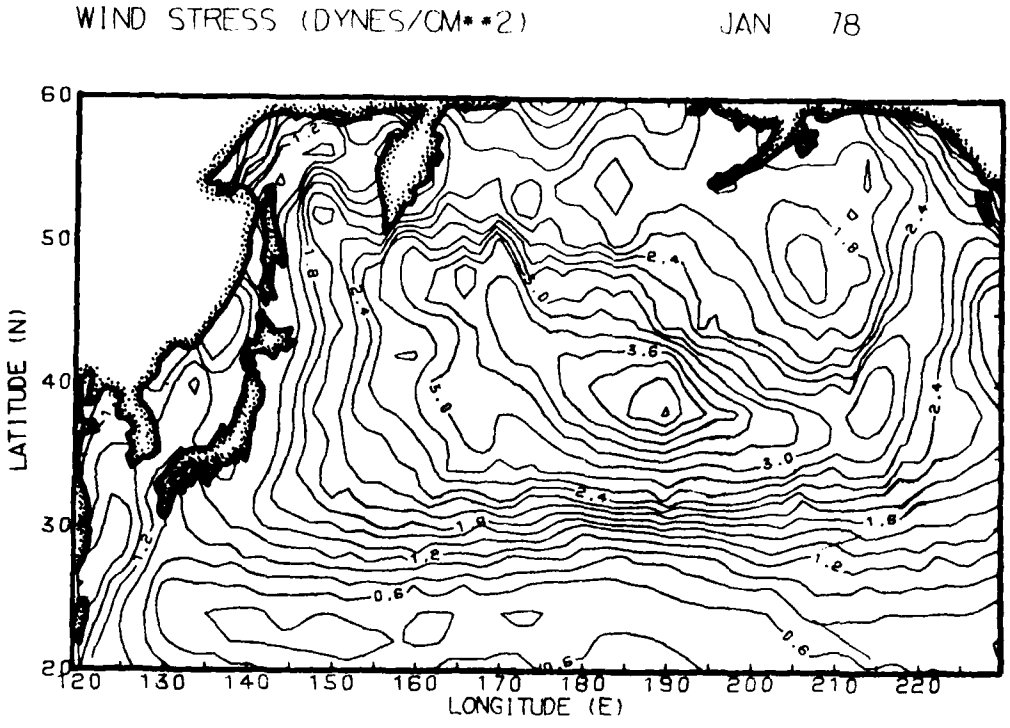


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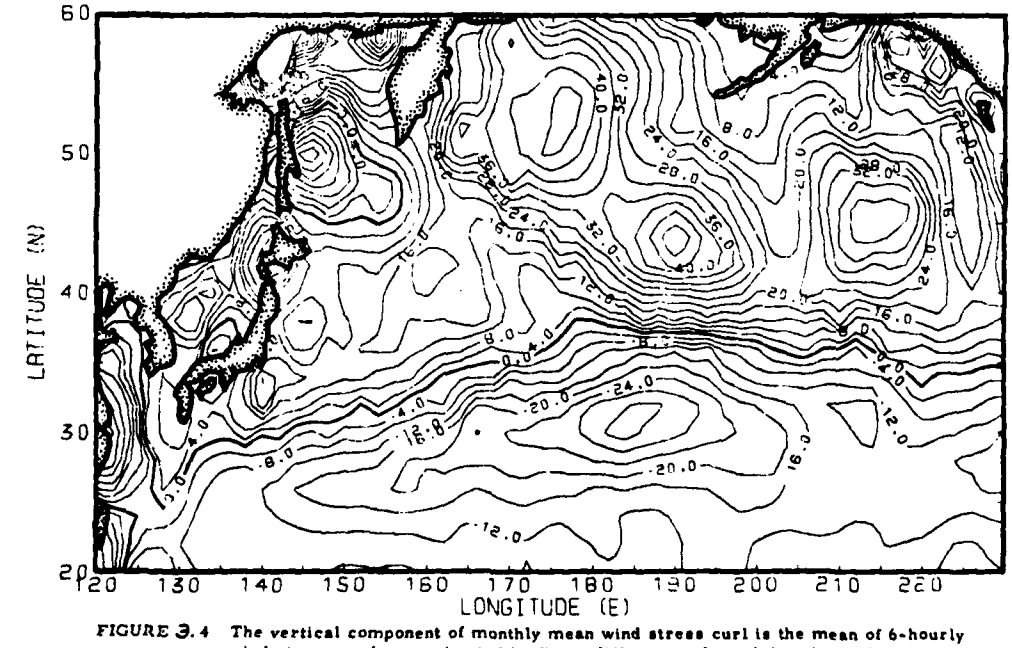


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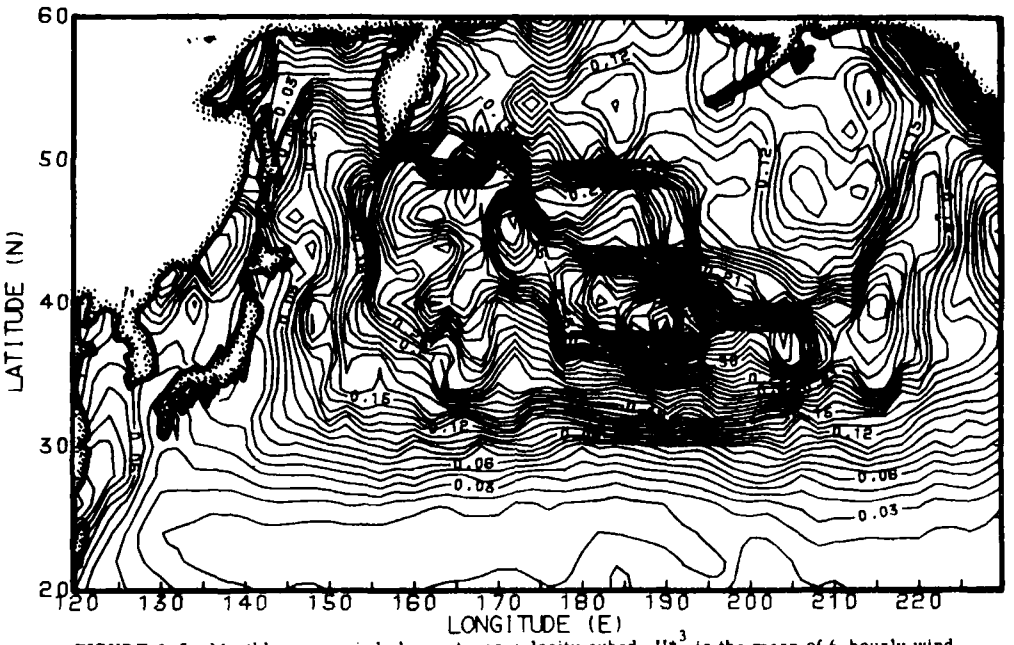


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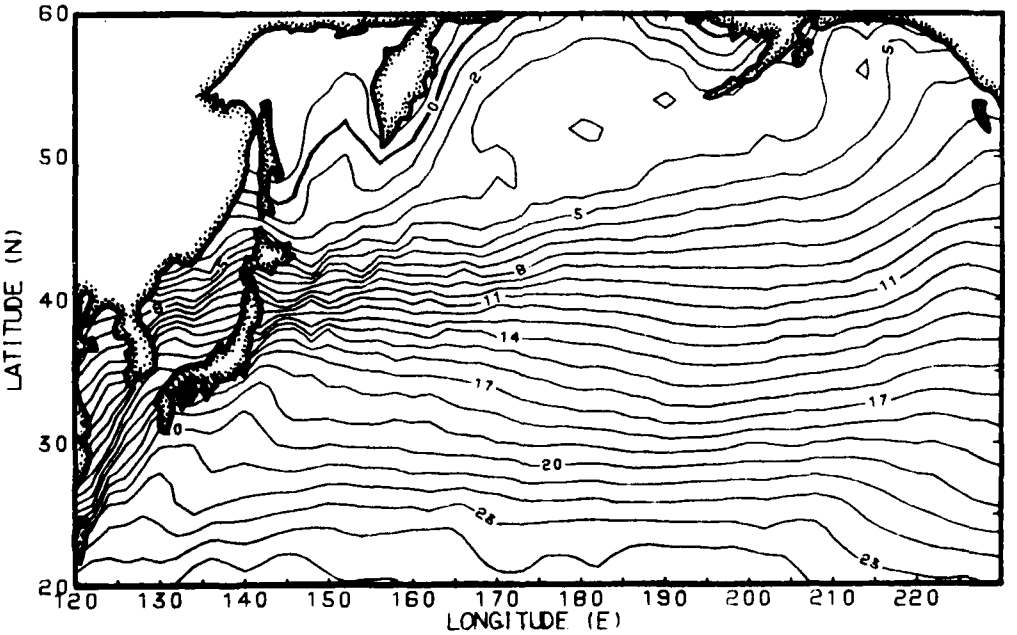


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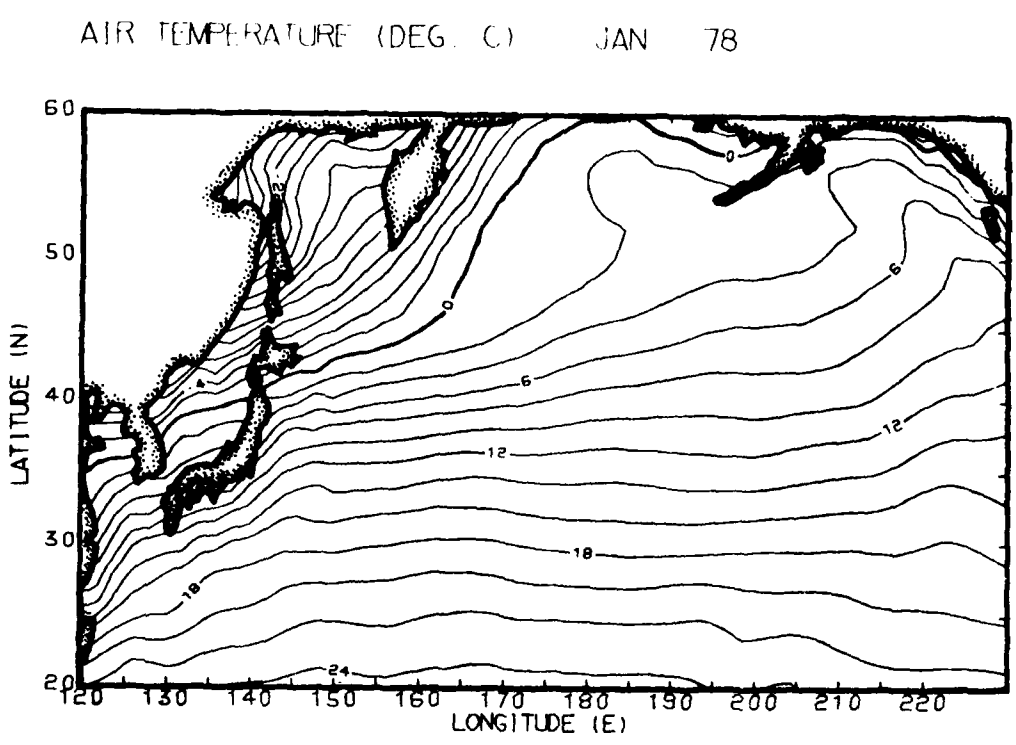


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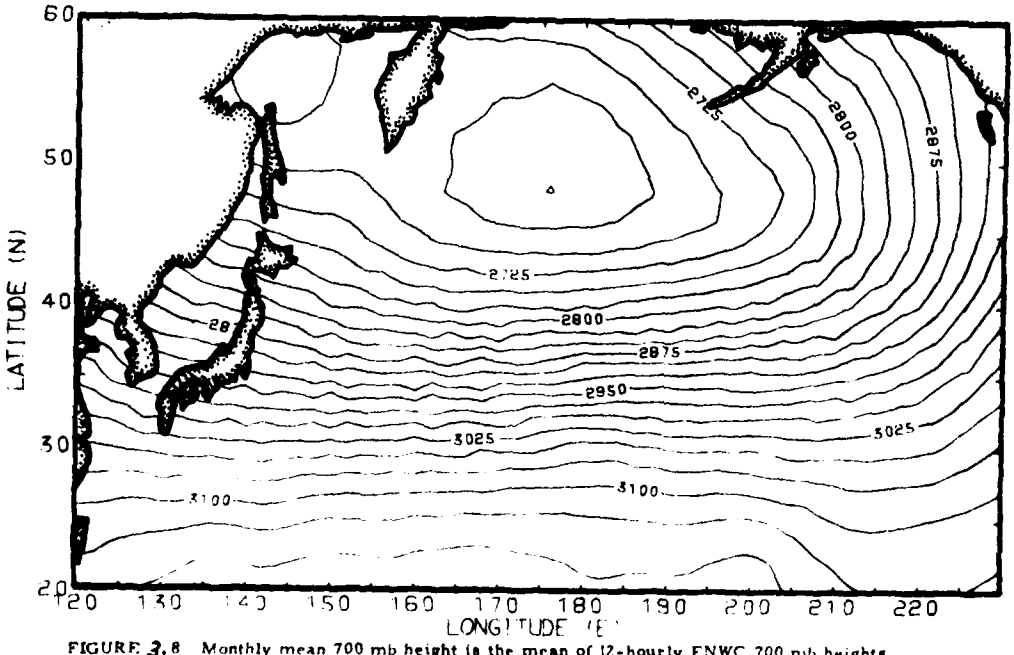


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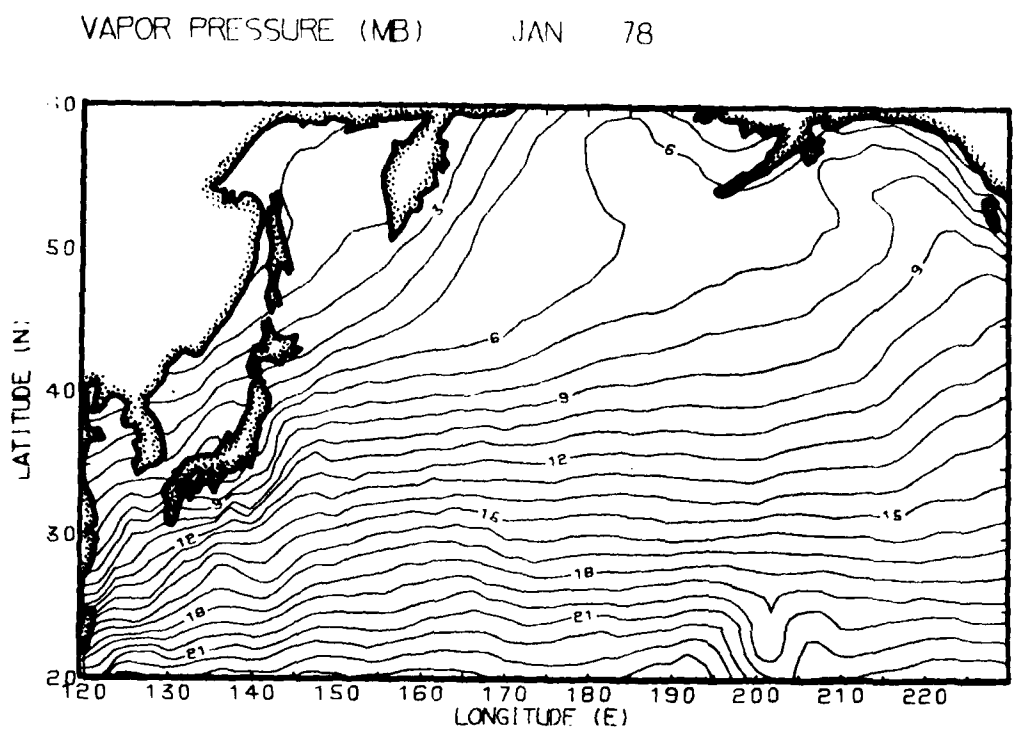


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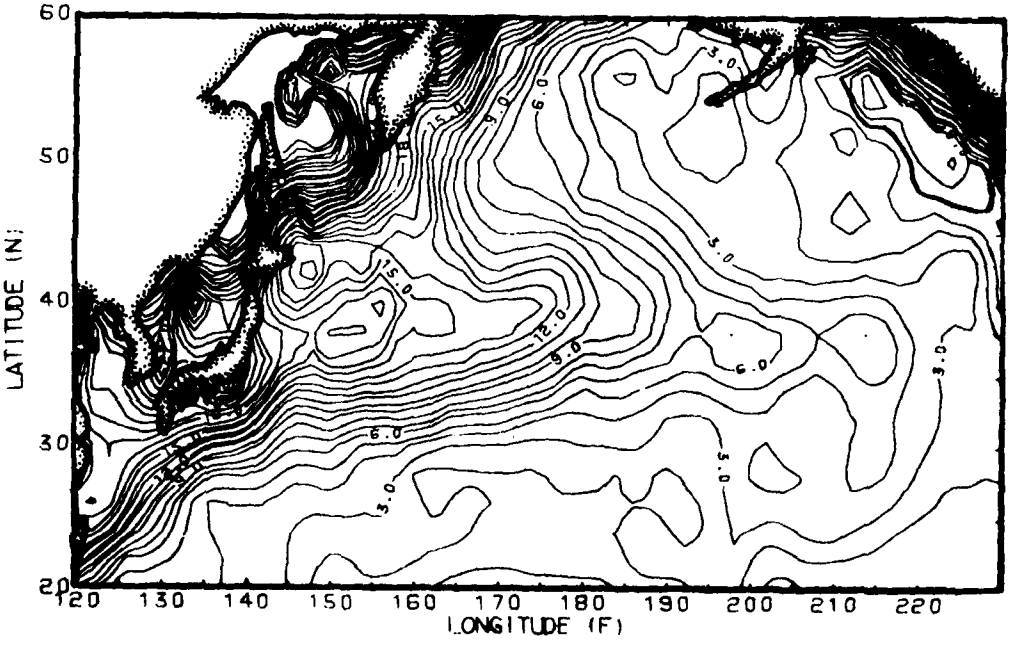


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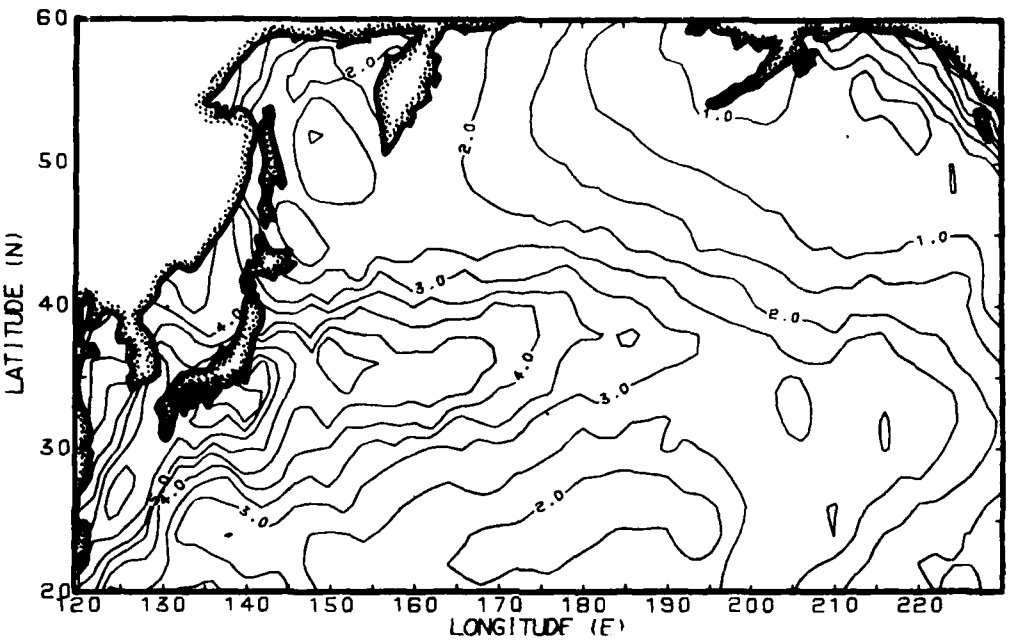


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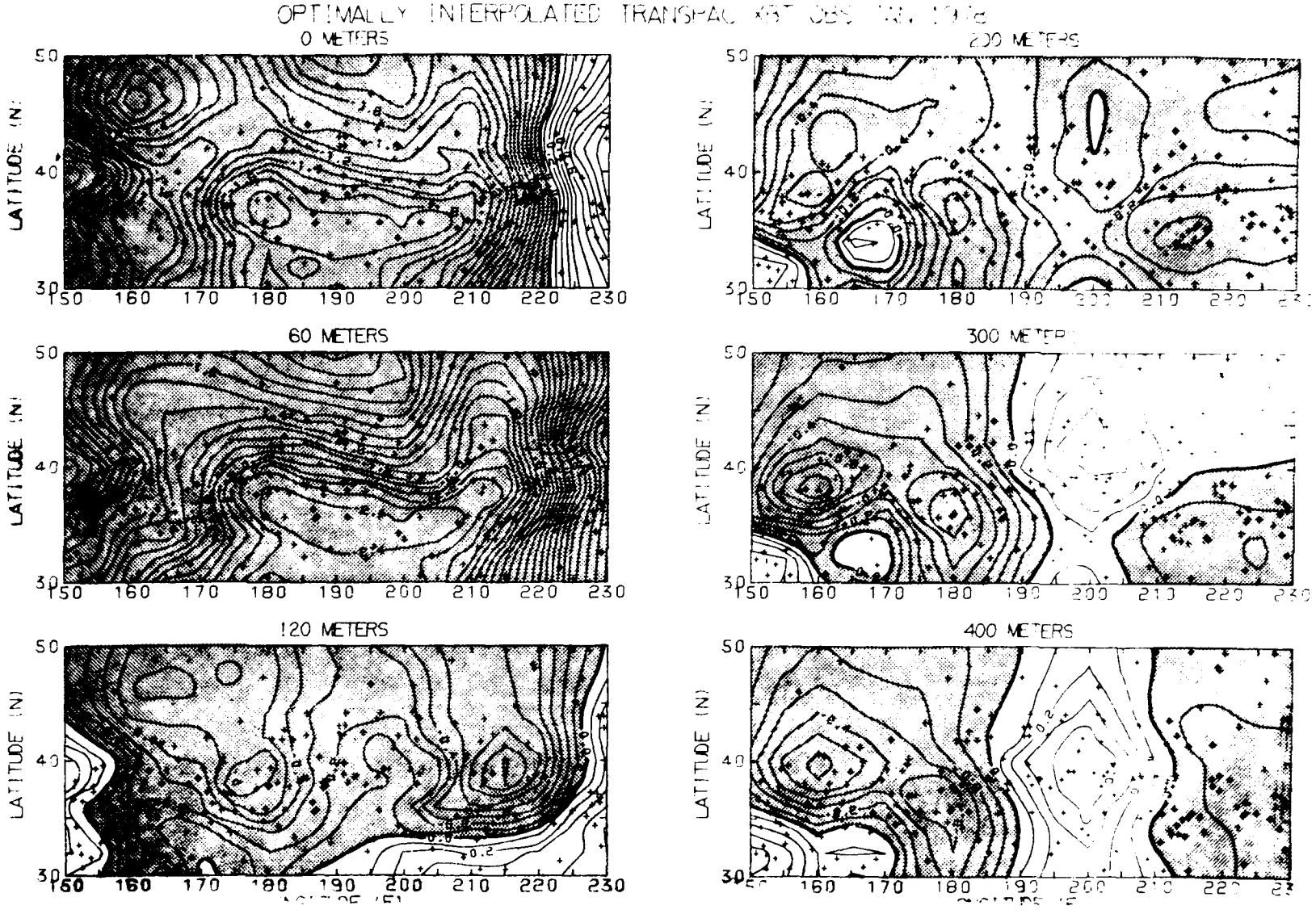


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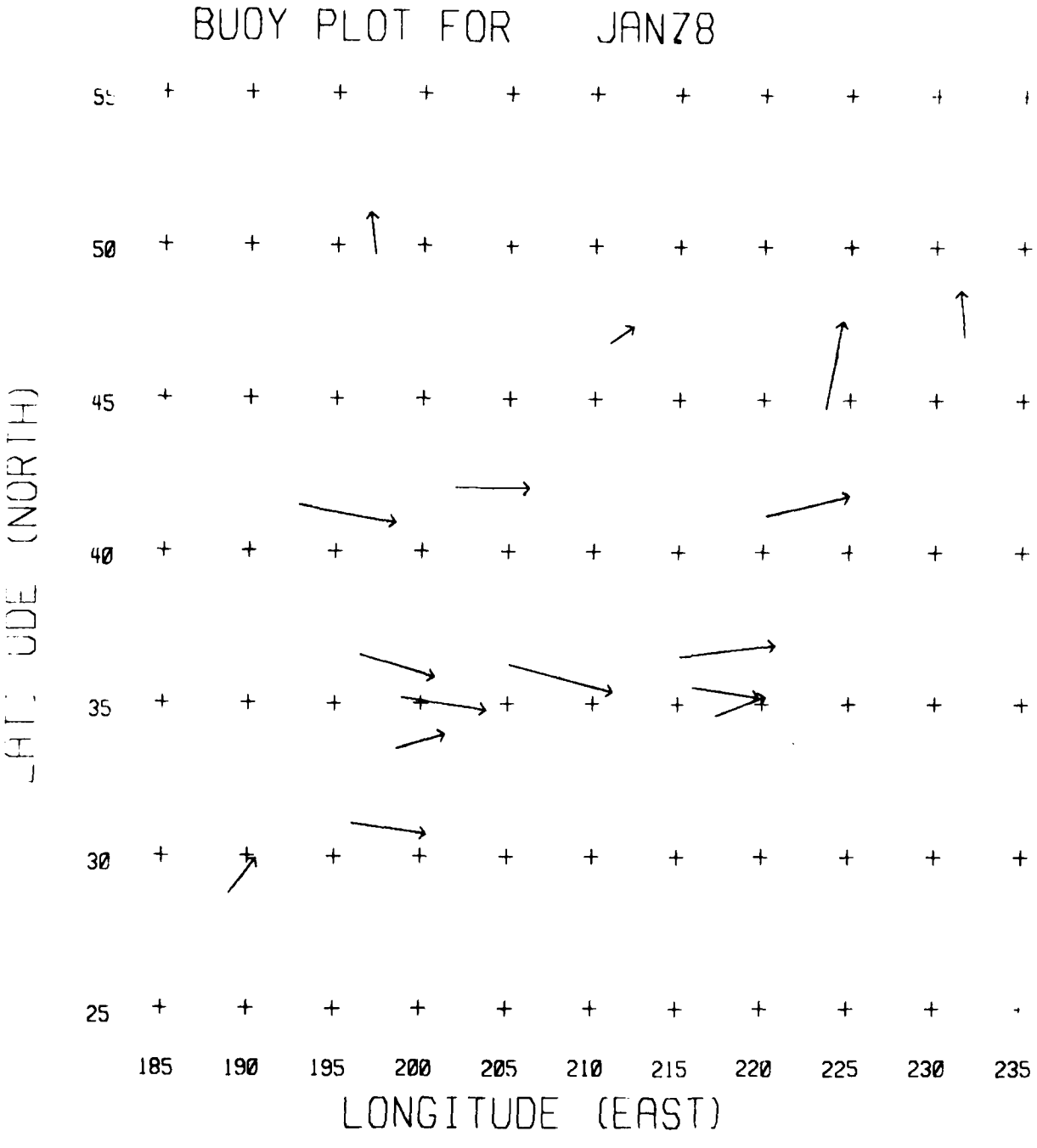


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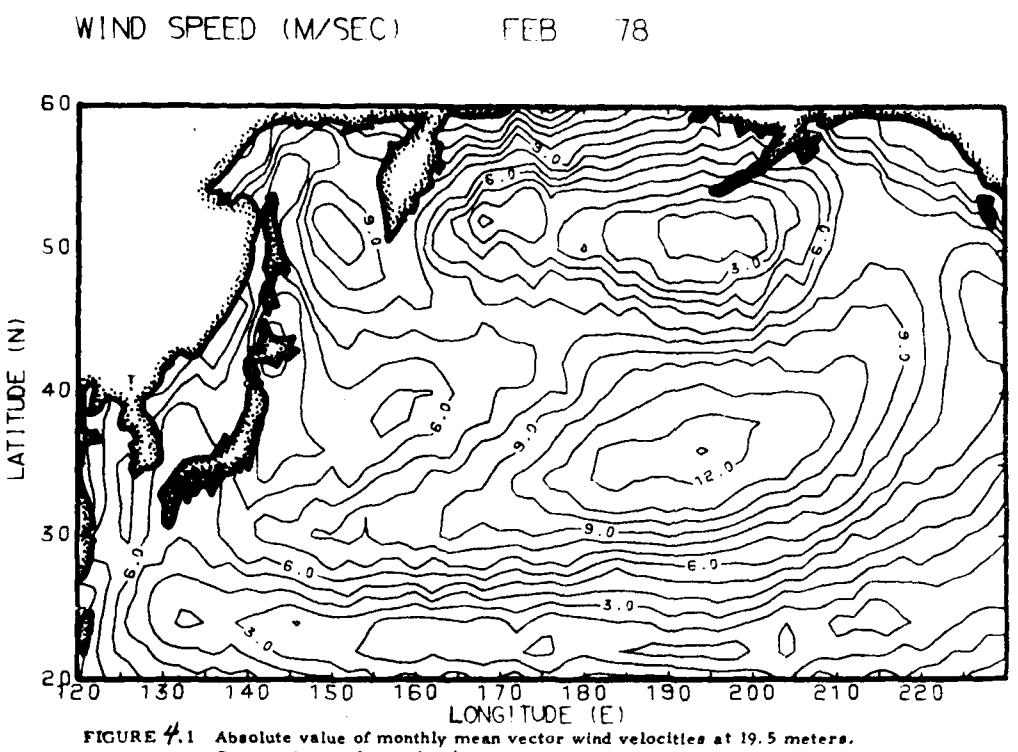


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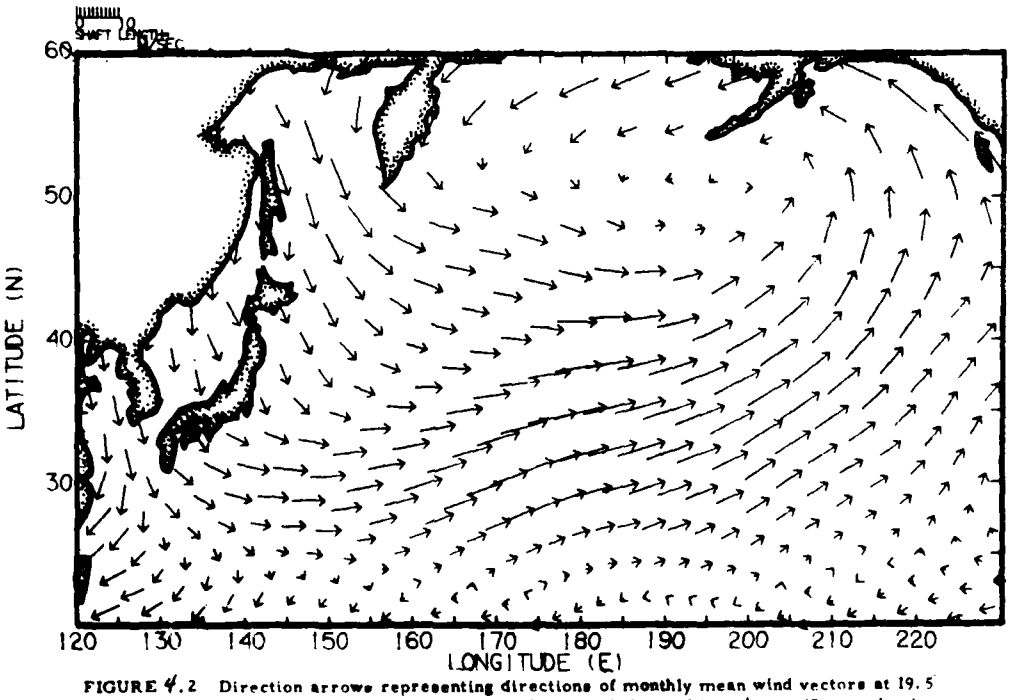


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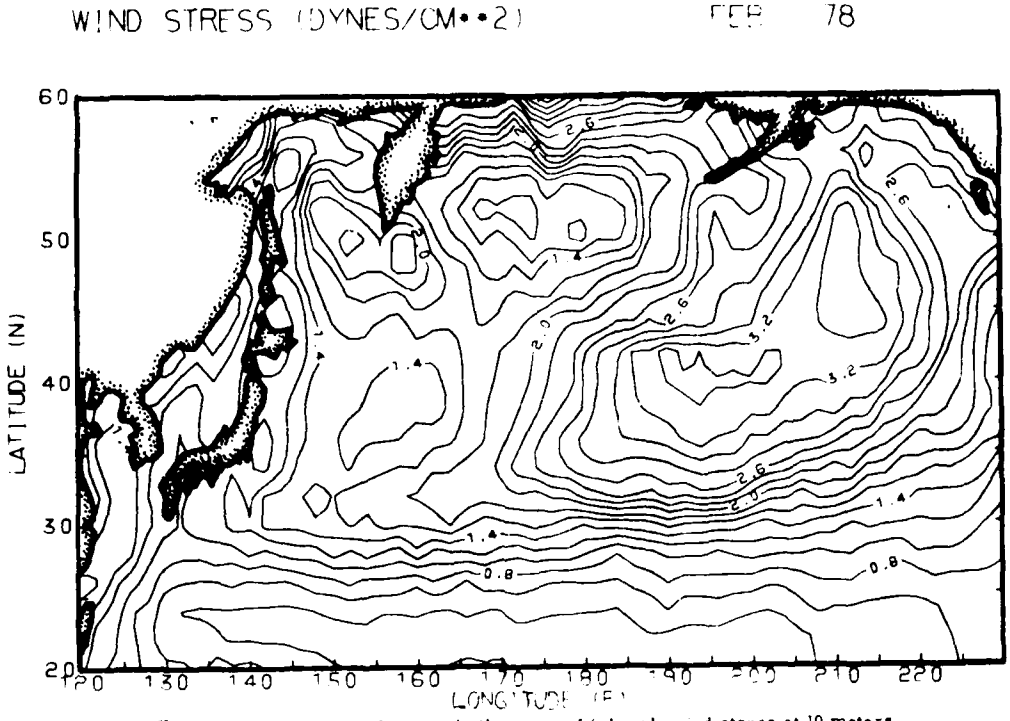


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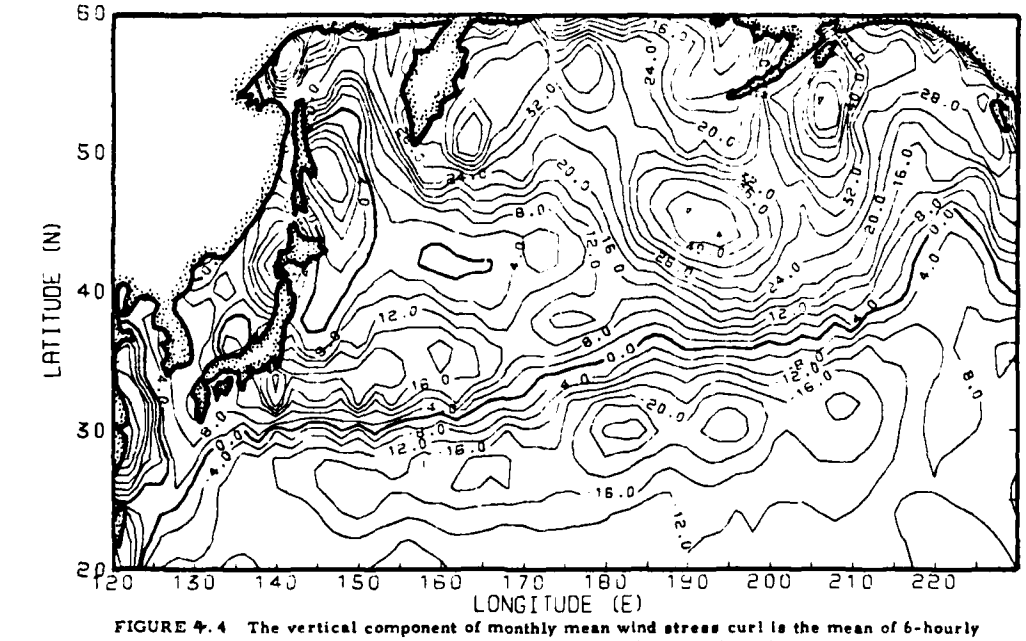


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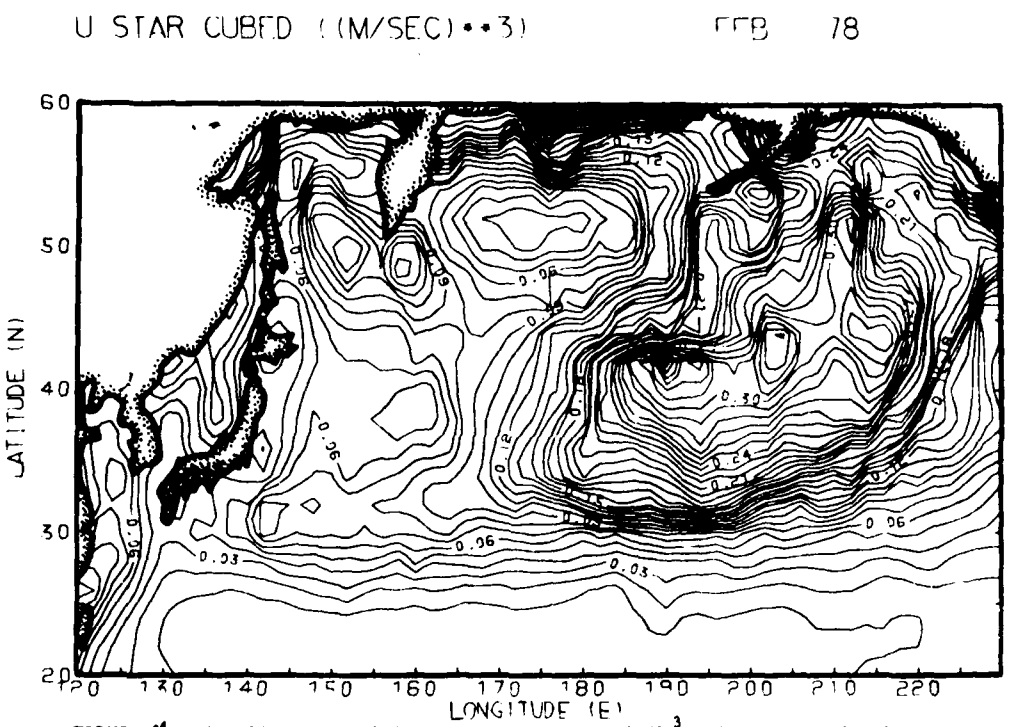


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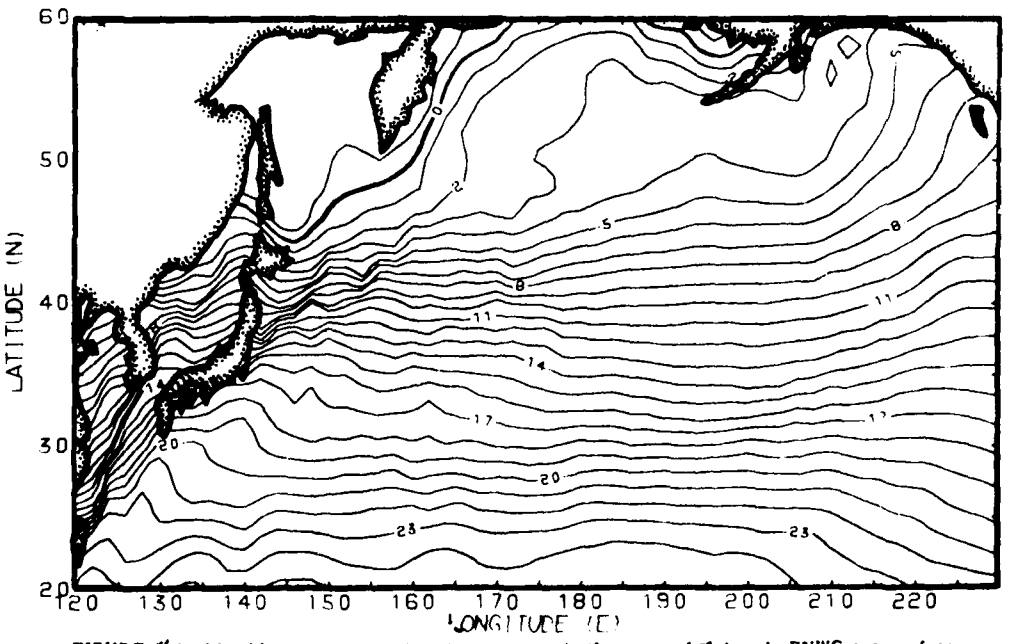


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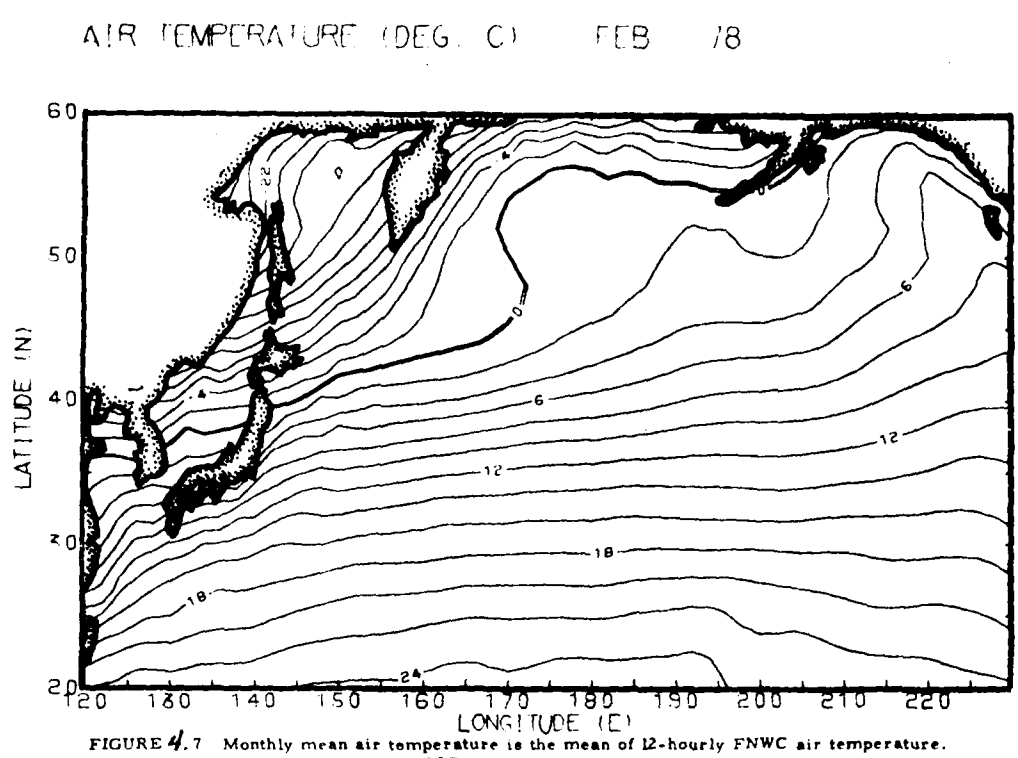



FIGURE 4.7 Monthly mean air temperature is the mean of 12-hourly FNWC air temperature. Contour intervals are 2°C.

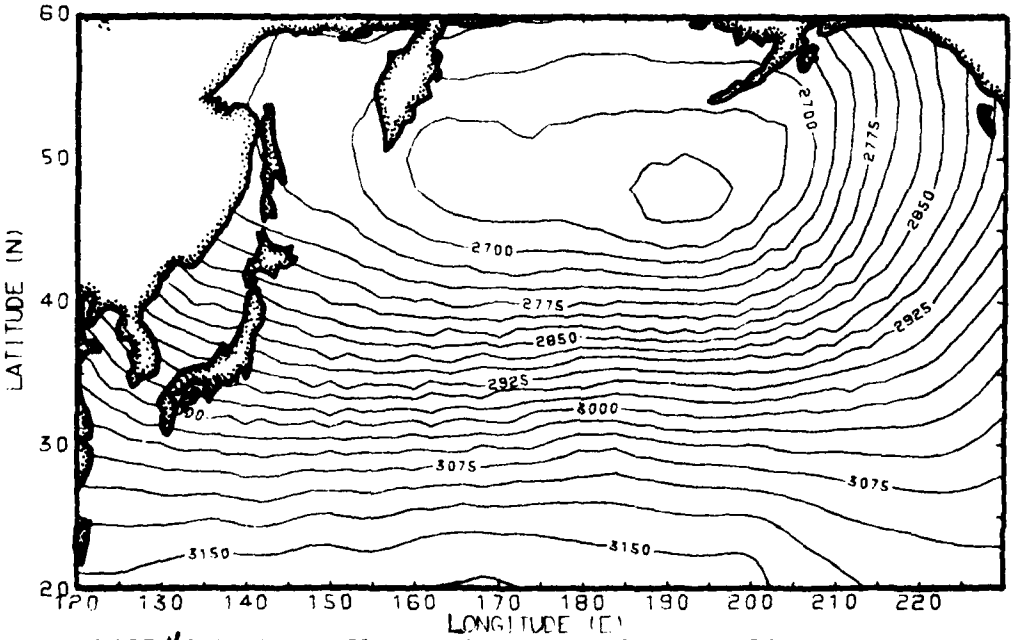



FIGURE 4.8 Monthly mean 700 mb height is the mean of 12-hourly FNWC 700 mb heights. Contour intervals are 25 meters.

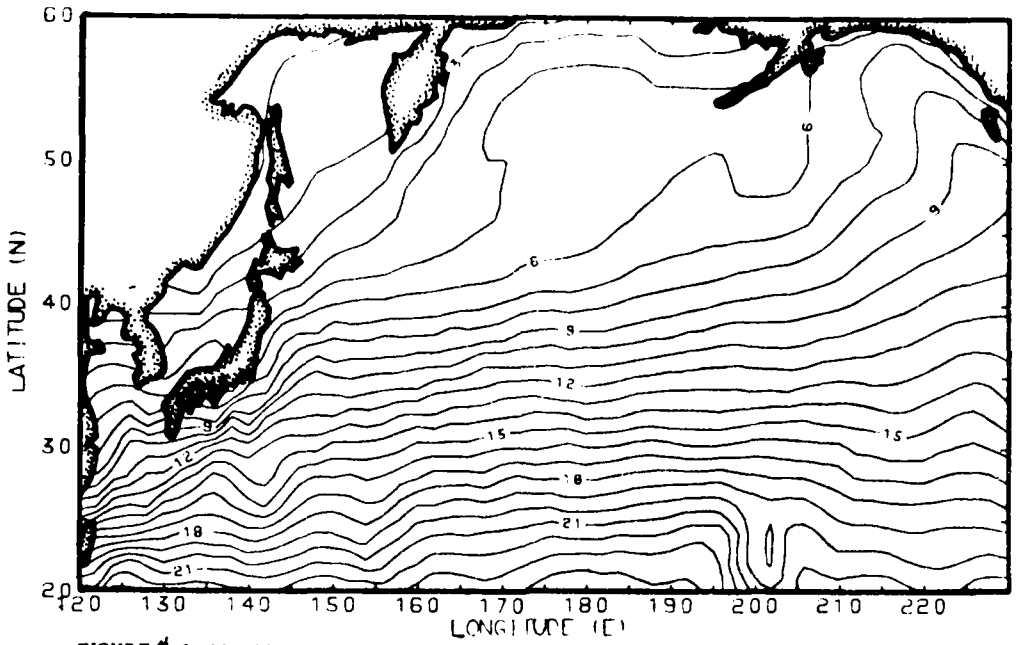



FIGURE 4.9 Monthly mean surface vapor pressure is the mean of 12-hourly FNWC vapor pressure at 19.5 meters. Contour intervals are 1 mb.

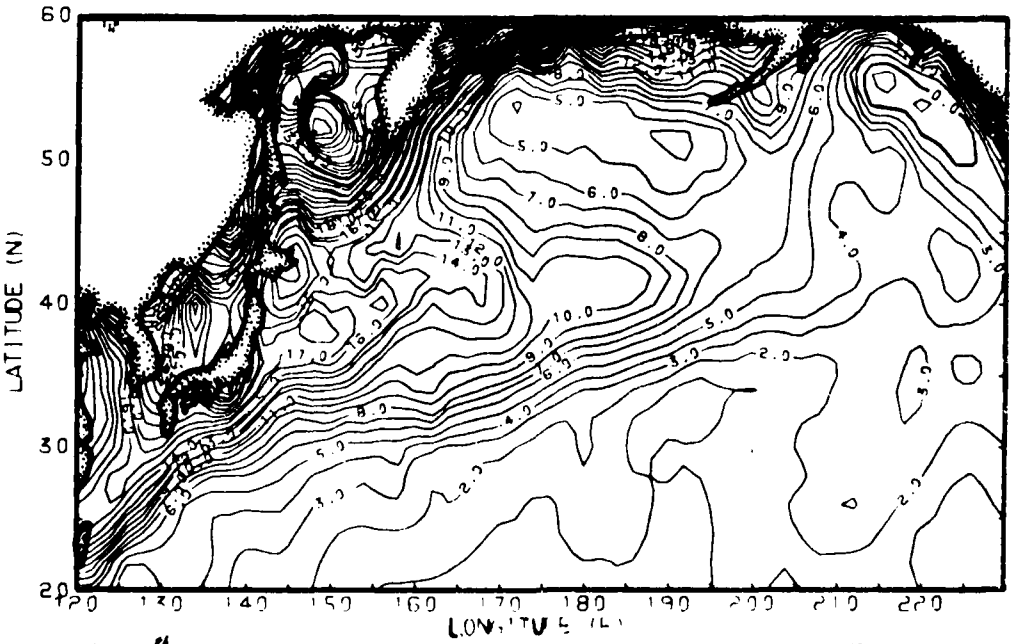



FIGURE 4.10 Monthly mean sensible heat flux (ocean to atmosphere) is the mean of 12-hourly sensible heat flux calculated from FNWC air and sea temperature and wind using a bulk formula. Isolines of zero heat flux are plotted heavily, and contour intervals are $1.0 \times 10^{-4}$ cal/cm$^2$ sec.

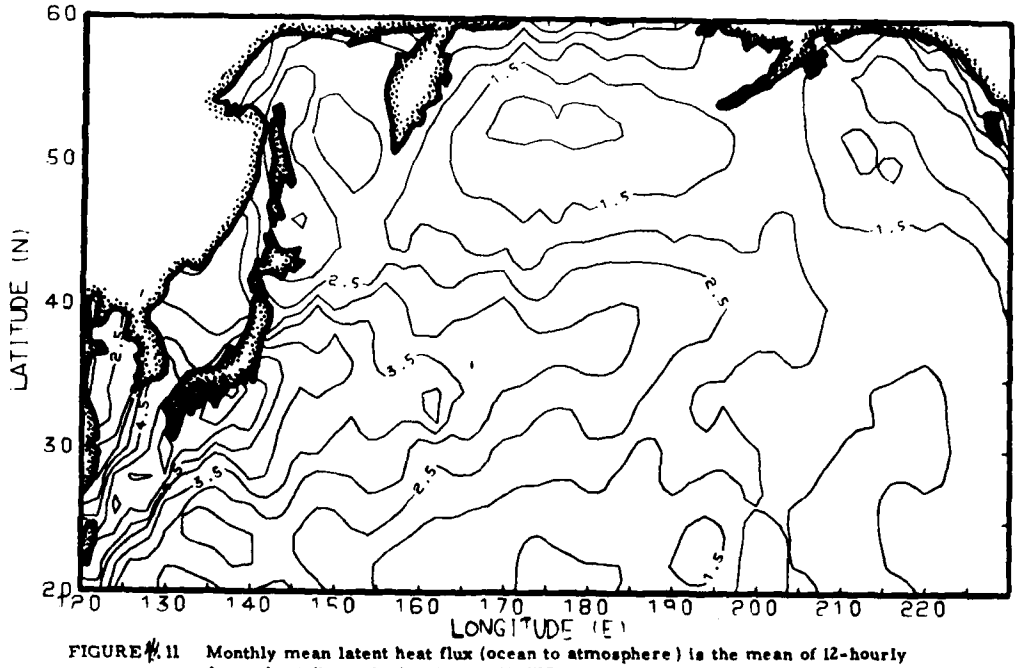



FIGURE 11 Monthly mean latent heat flux (ocean to atmosphere) is the mean of 12-hourly latent heat flux calculated from FNWC sea temperature, vapor pressure and wind using a bulk formula. Isoline of zero heat flux are plotted heavily, and contour intervals are $0.5 \times 10^{-3}$ cal/cm$^2$ sec.

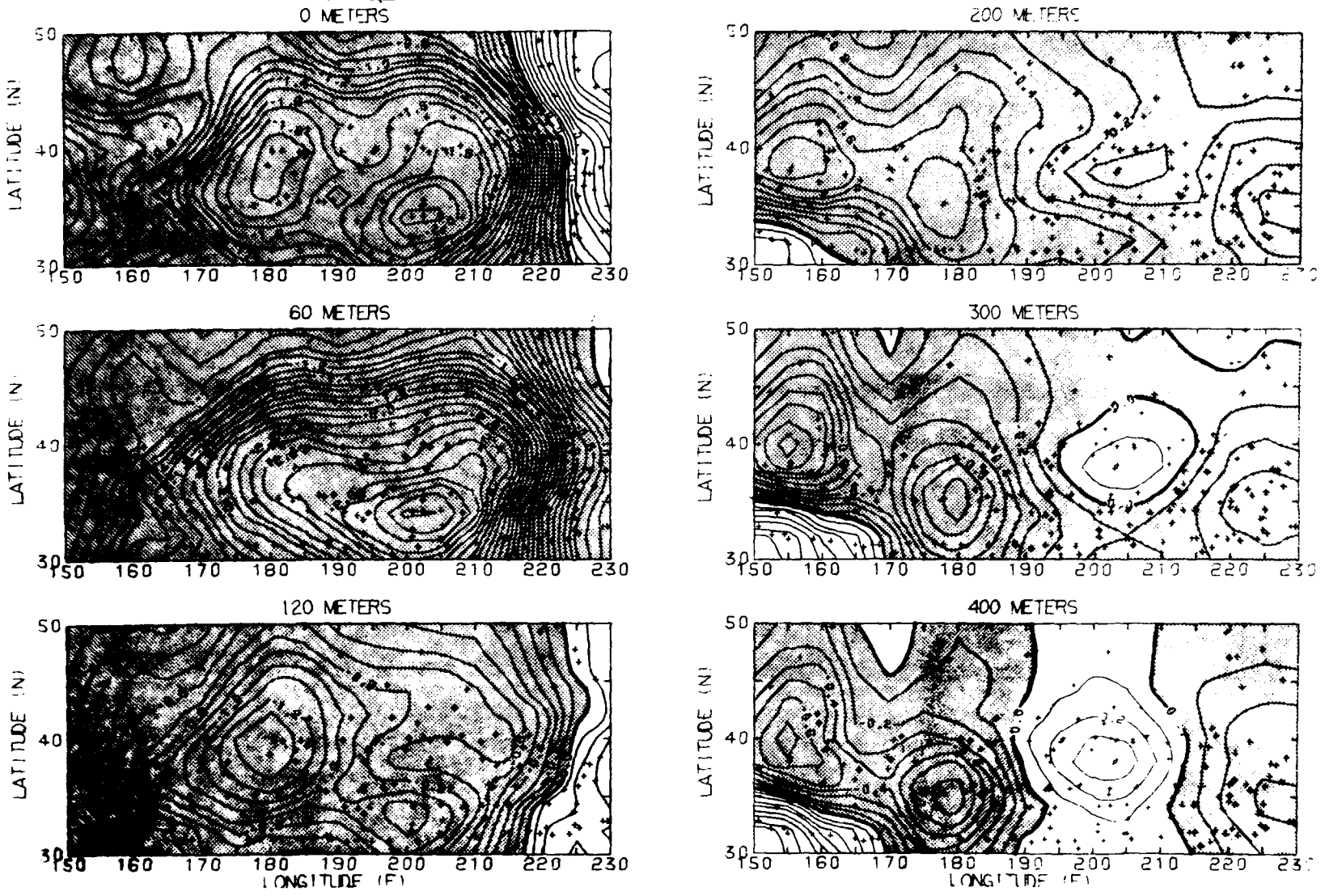



FIGURE 4.12 Monthly temperature anomalies (°C) contoured at fixed depths. Negative anomaly areas are hatchured and isoline of zero anomaly are drawn heavily. The crosses mark the positions of the TRANSPAC XBT drops. Increments are in .1°C (prepared by W. White, SIO).

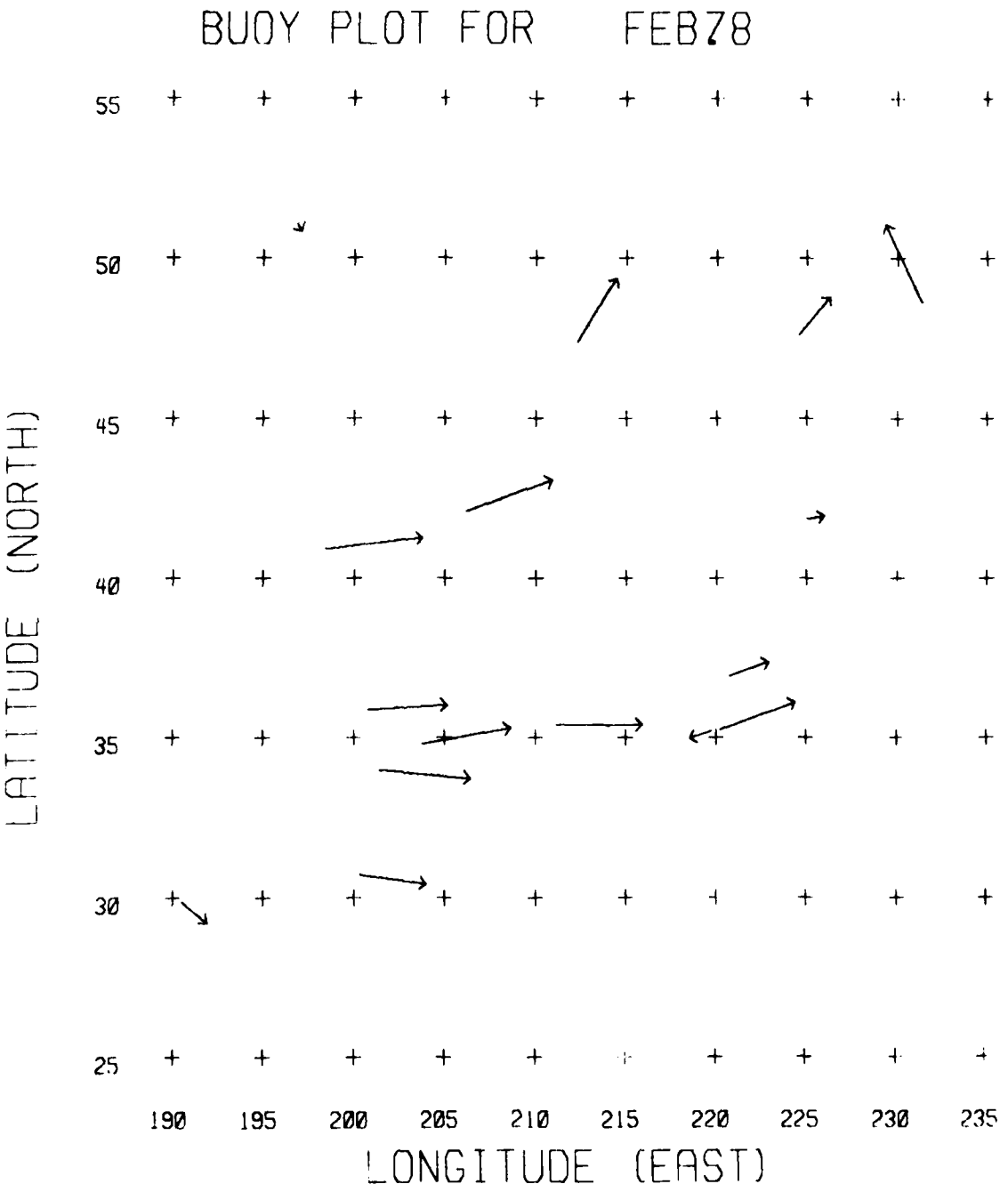



FIGURE 4.13 Monthly buoy tracks. Tracks are drawn from starting point at beginning of month to terminal point at end of month. Ratio of latitude to longitude is the same as in other figures.

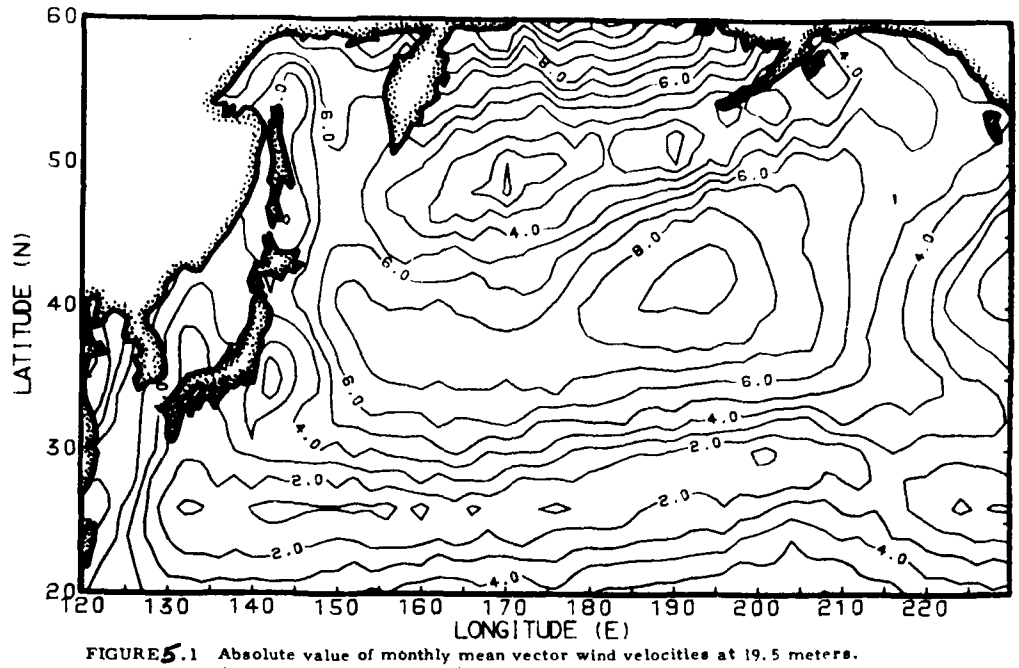



FIGURE 5.1 Absolute value of monthly mean vector wind velocities at 19.5 meters. Contour intervals are 1 m/sec.

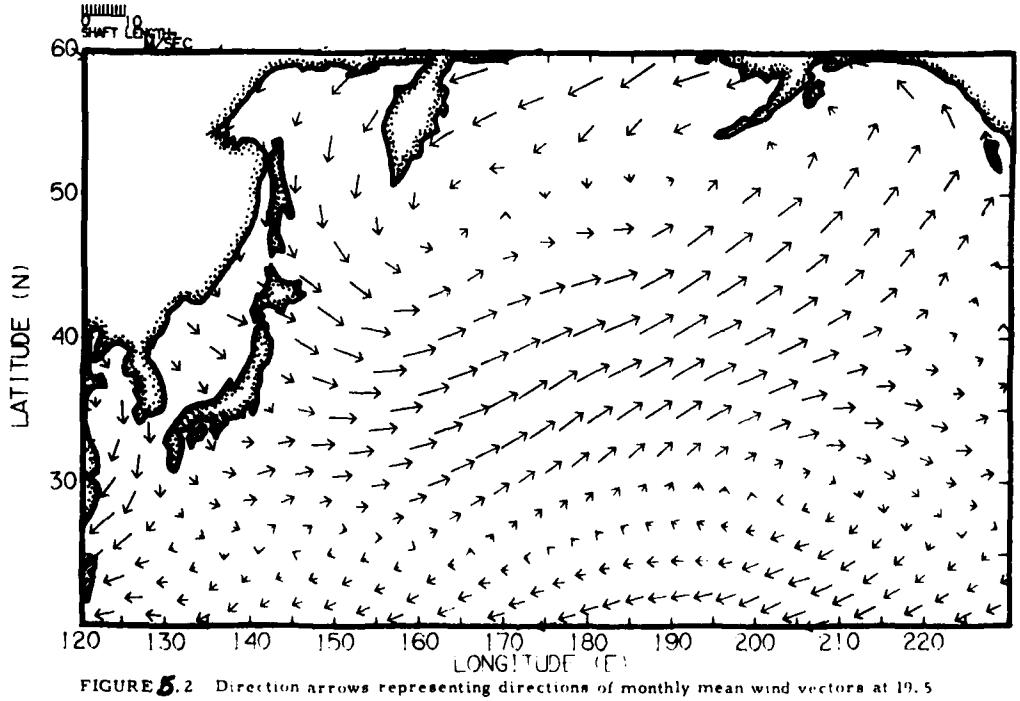



FIGURE 5.2 Direction arrows representing directions of monthly mean wind vectors at 19.5 meters. Length of arrow shaft indicates wind speed in m/sec. (See scale above figure).

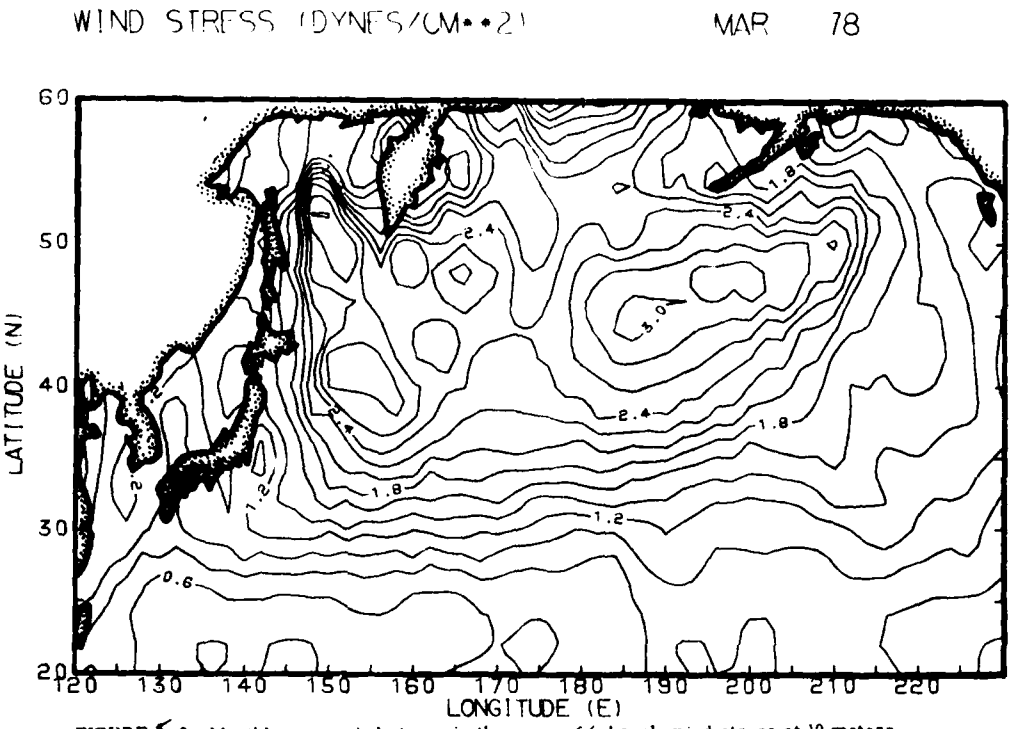
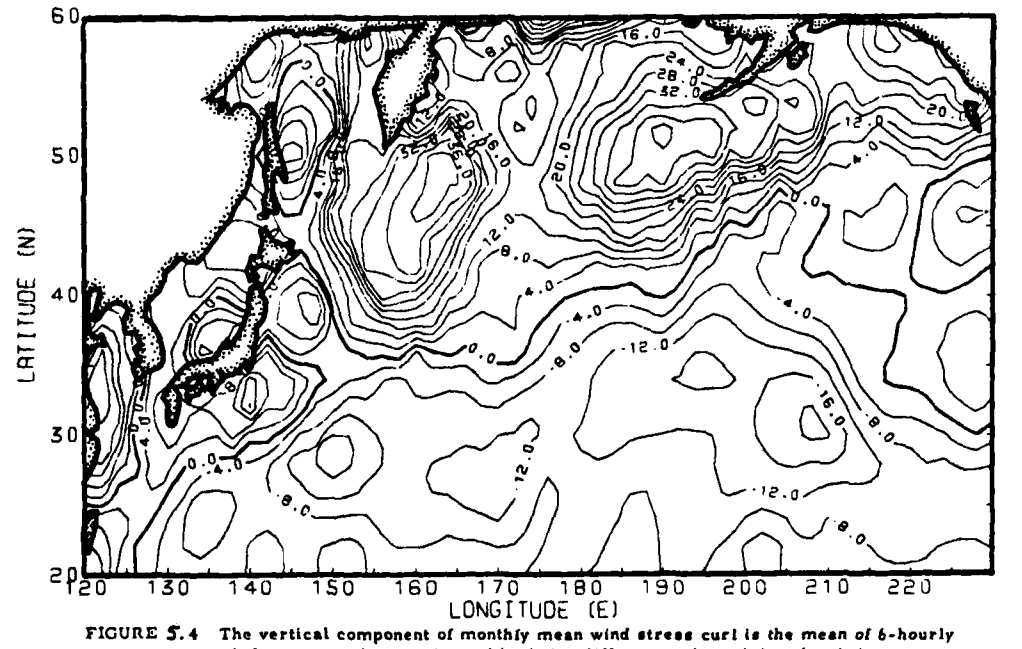



FIGURE 5.3 Monthly mean wind stress is the mean of 6-hourly wind stress at 10 meters calculated from FNWC wind data. Contour intervals are 0.2 dynes/cm$^2$.

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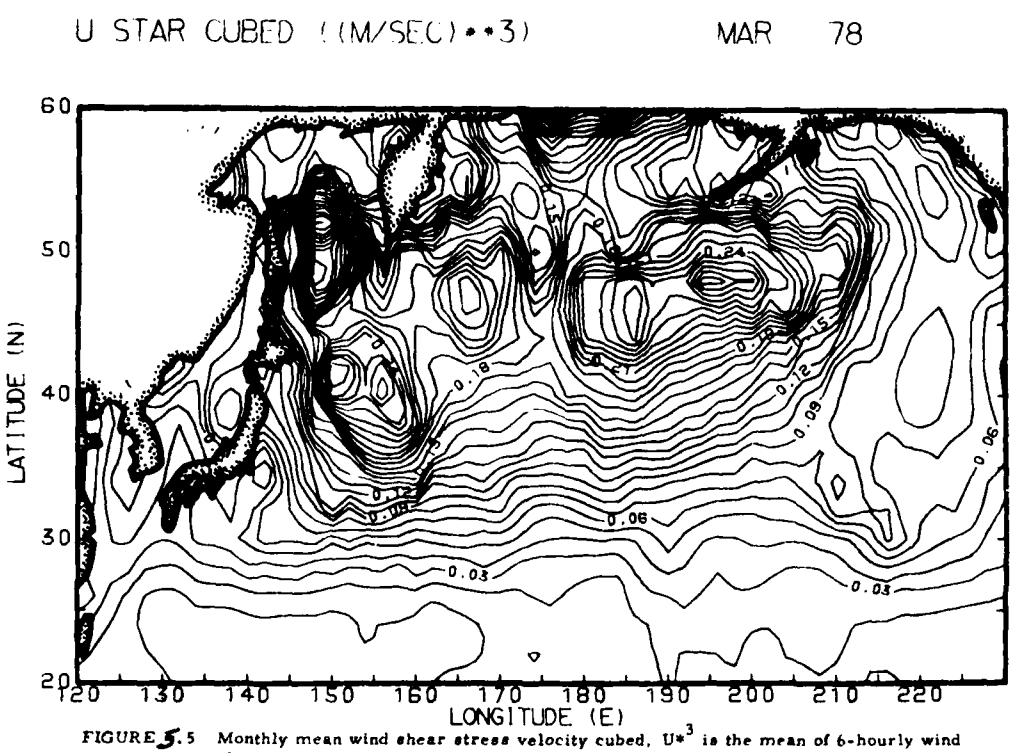



FIGURE 5.5 Monthly mean wind shear stress velocity cubed, $U^{*3}$ is the mean of 6-hourly wind shear stress velocity cubed calculated from wind speed at 10 meters. Contour intervals are 0.02 $(m/sec)^3$.

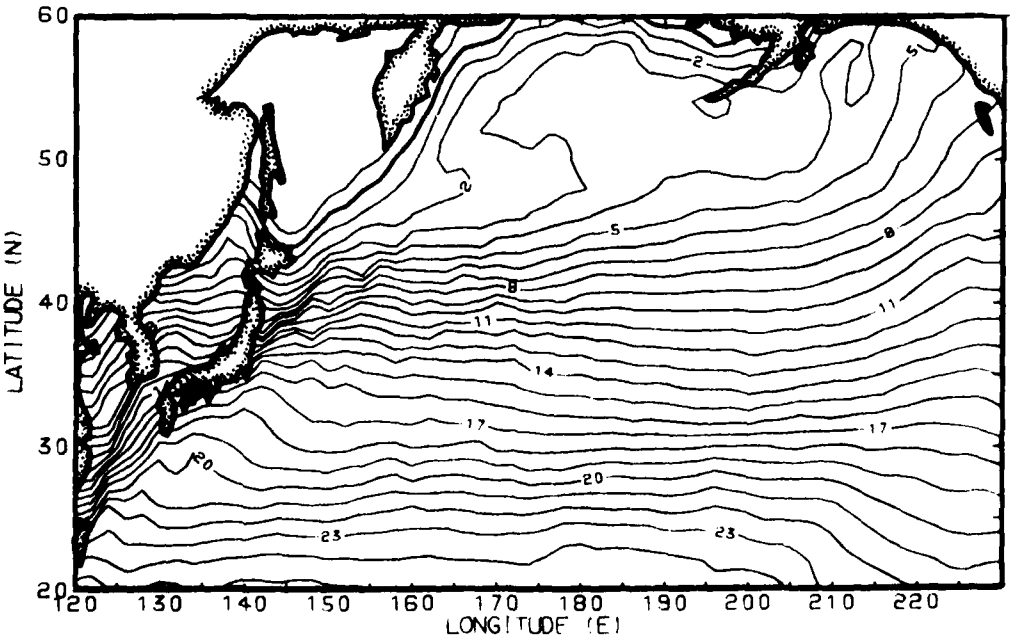



FIGURE 5.6 Monthly mean sea surface temperature is the mean of 12-hourly FNWC sea surface temperatures. Contour intervals are 1°C.

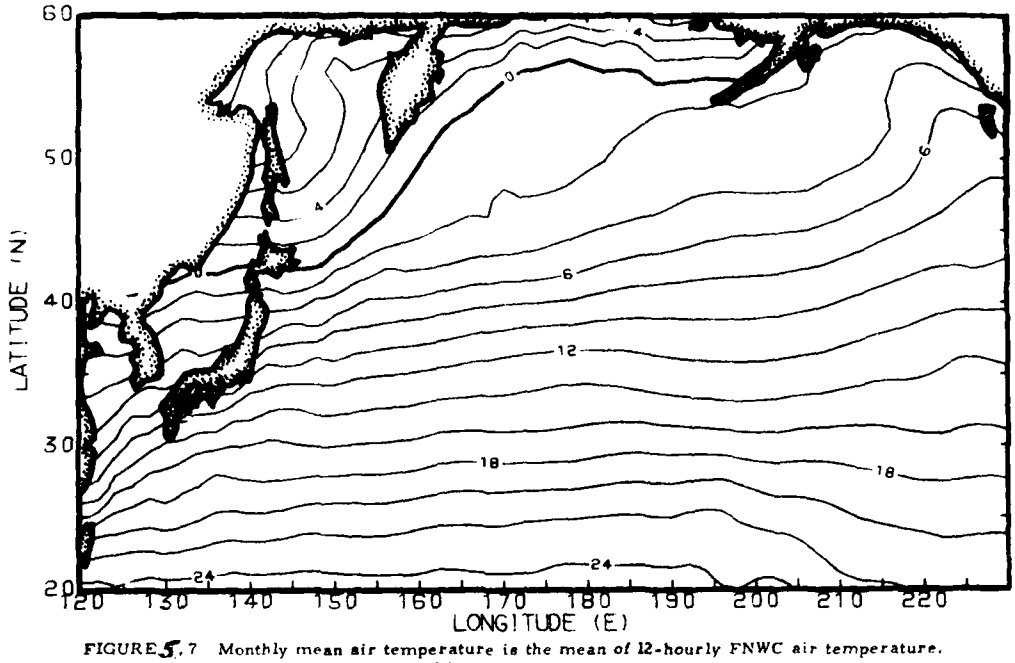



FIGURE 5.7 Monthly mean air temperature is the mean of 12-hourly FNWC air temperature. Contour intervals are 2°C.

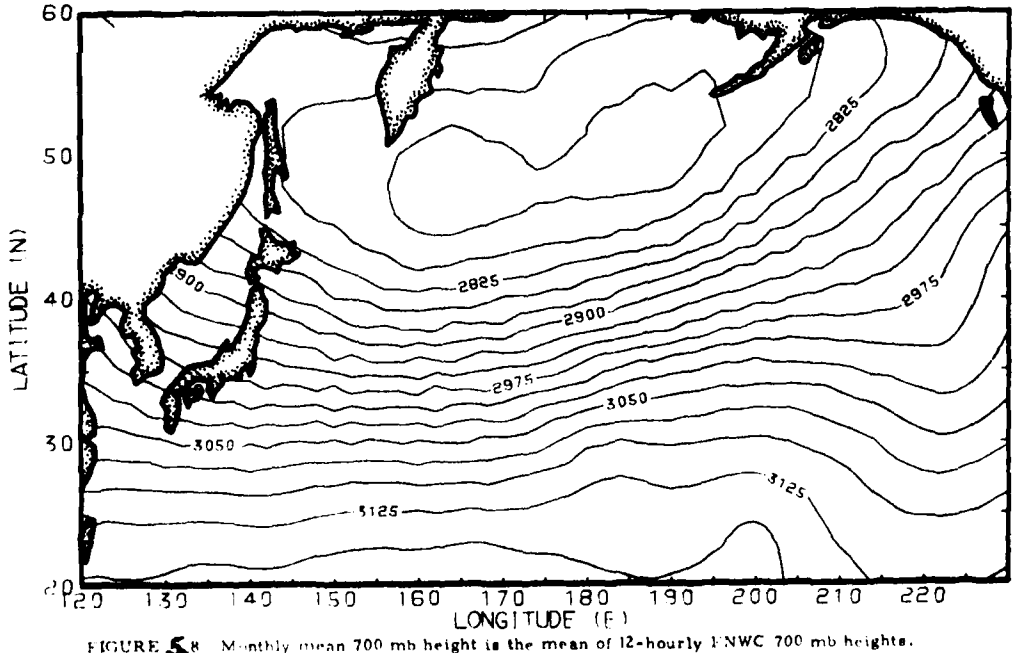



FIGURE 5.8 Monthly mean 700 mb height is the mean of 12-hourly FNWC 700 mb heights. Contour intervals are 25 meters.

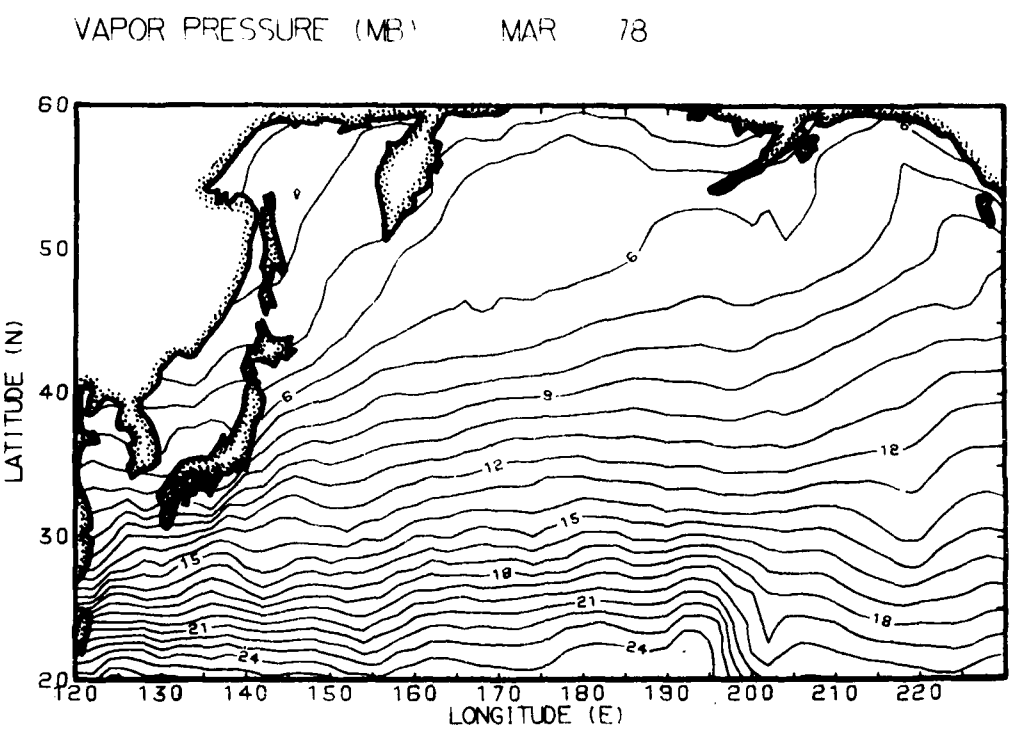



FIGURE 5.9 Monthly mean surface vapor pressure is the mean of 12-hourly FNWC vapor pressure at 19.5 meters. Contour intervals are 1 mb.

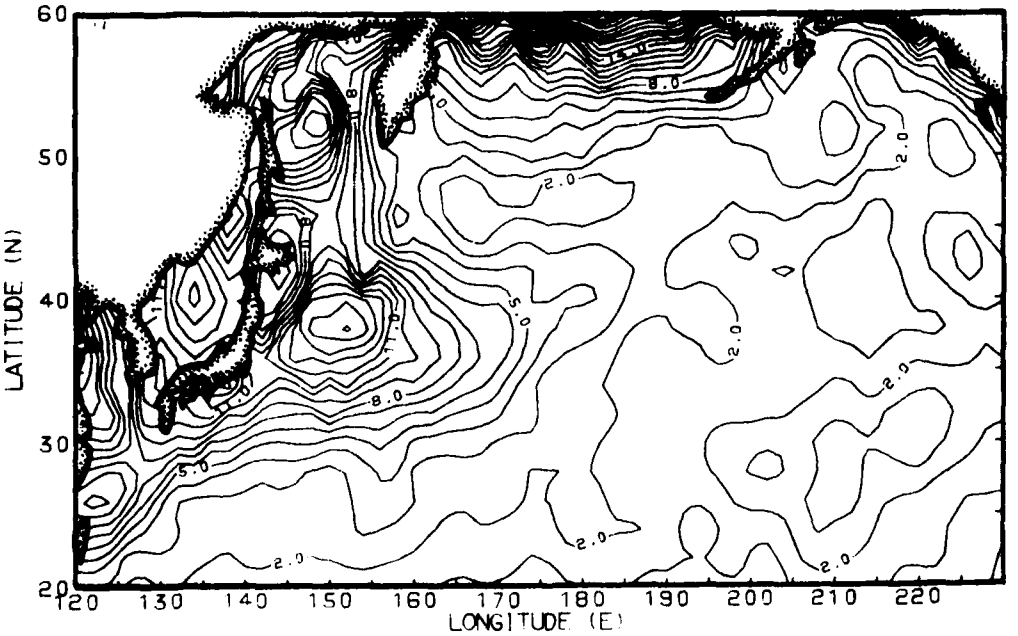



FIGURE 5.10 Monthly mean sensible heat flux (ocean to atmosphere) is the mean of 12-hourly sensible heat flux calculated from FNWC air and sea temperature and wind using a bulk formula. Isolines of zero heat flux are plotted heavily, and contour intervals are $1.0 \times 10^{-4}$ cal/cm$^2$ sec.

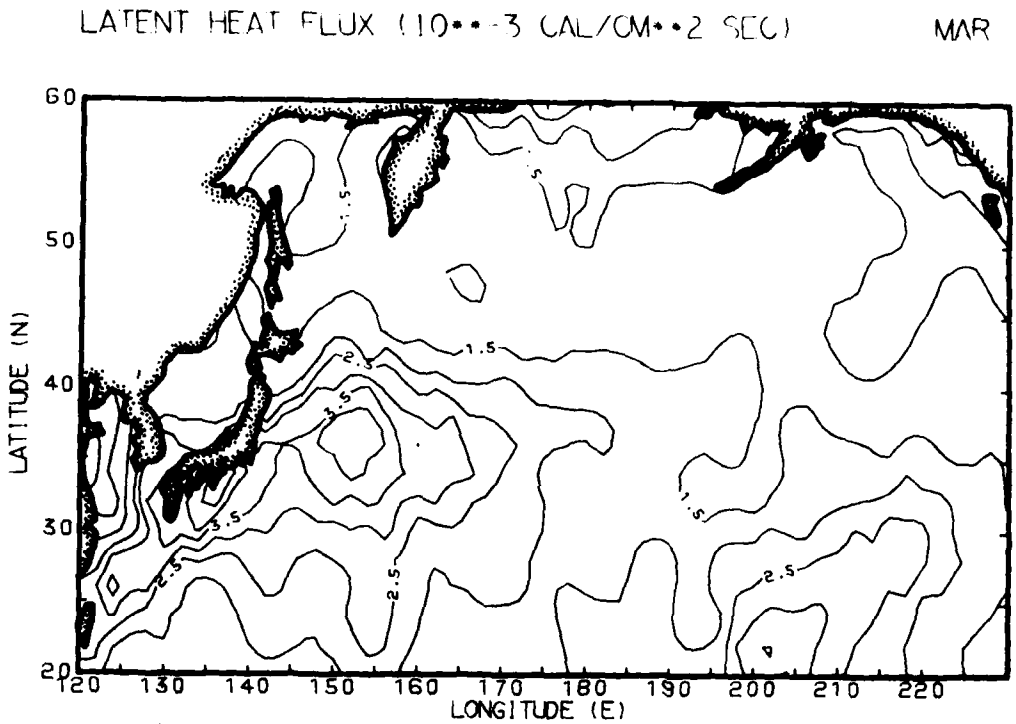



FIGURE 5.11 Monthly mean latent heat flux (ocean to atmosphere) is the mean of 12-hourly latent heat flux calculated from FNWC sea temperature, vapor pressure and wind using a bulk formula; Isoline of zero heat flux are plotted heavily, and contour intervals are $0.5 \times 10^{-3}$ cal/cm$^2$ sec.

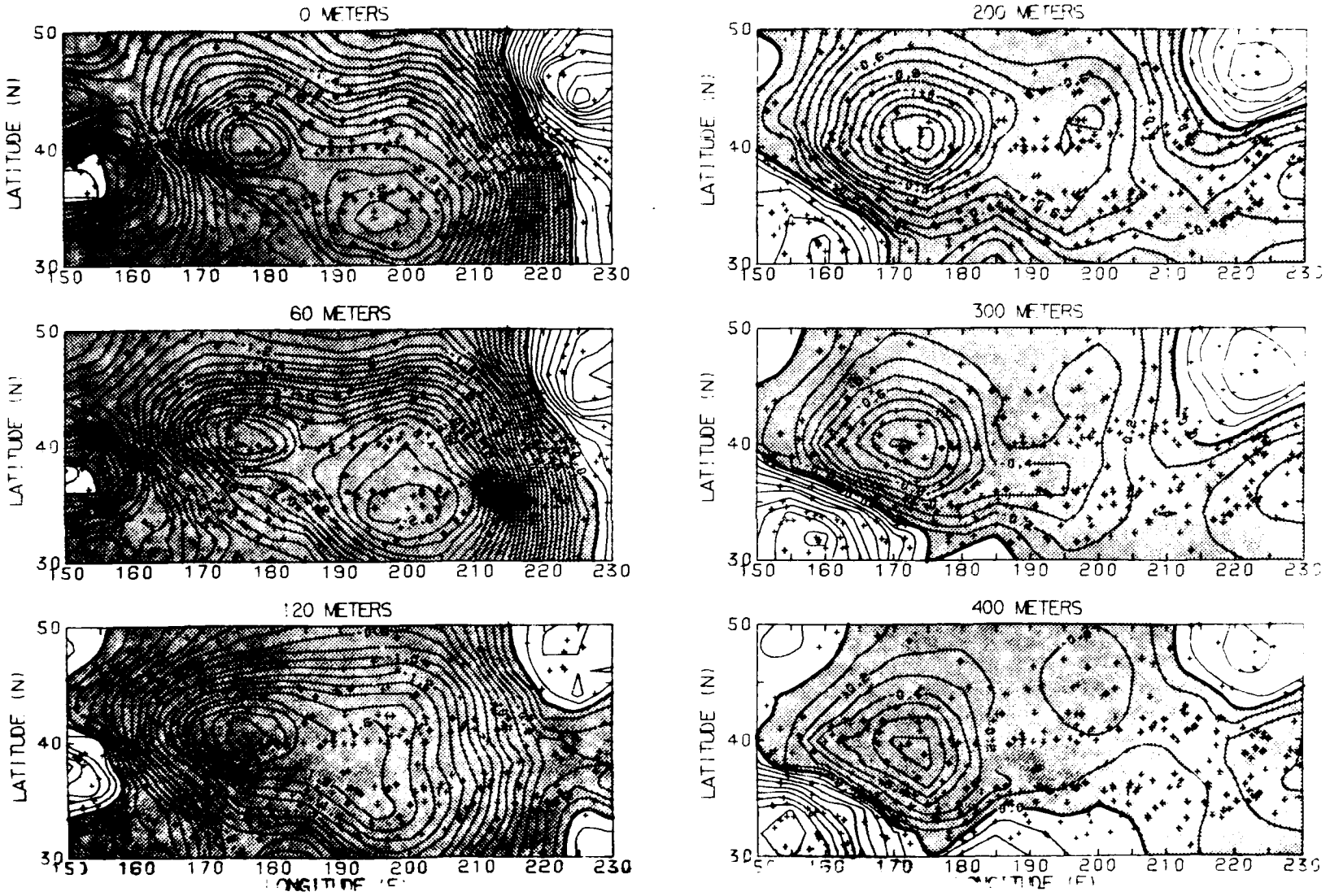
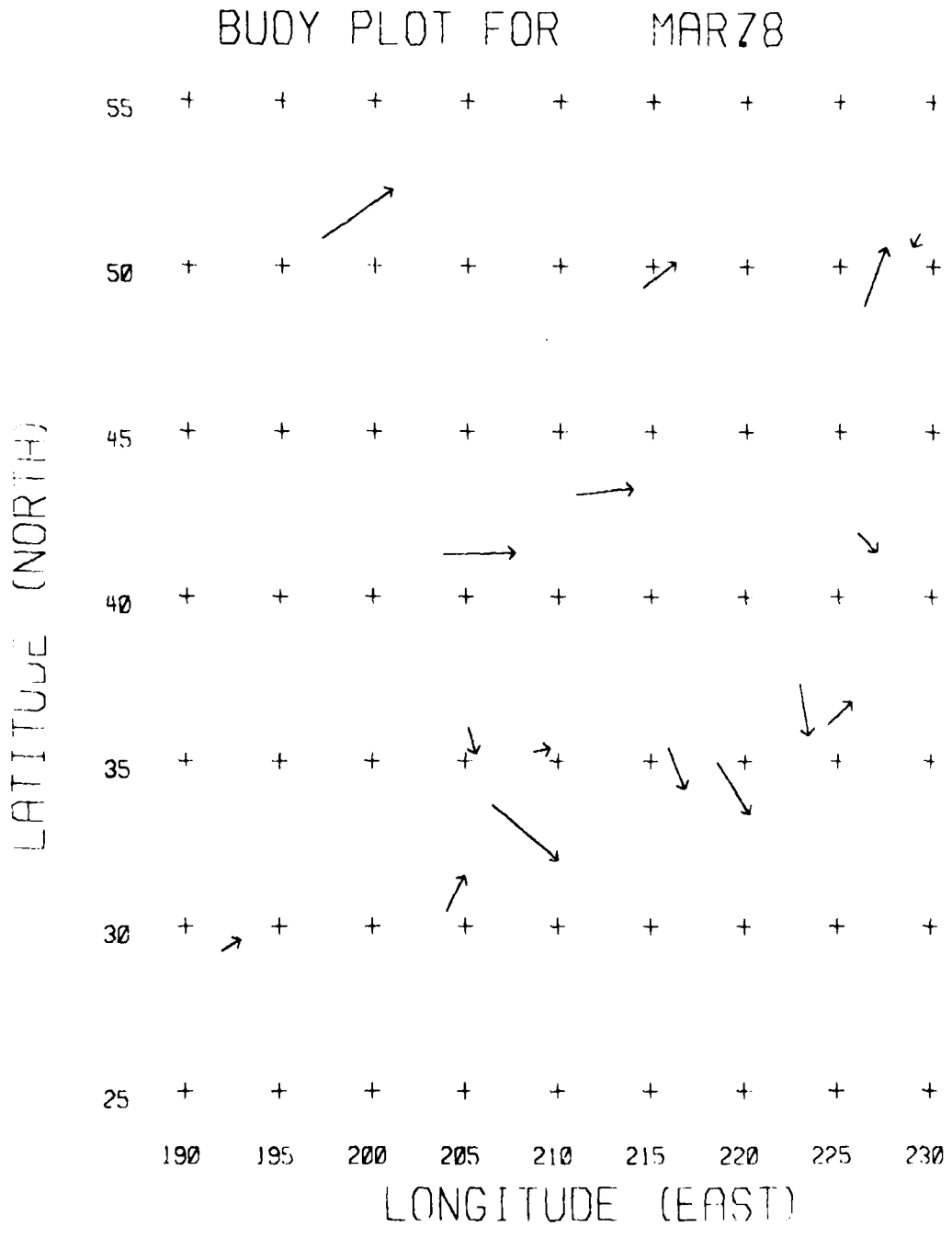



FIGURE 5.12 Monthly temperature anomalies (°C) contoured at fixed depths. Negative anomaly areas are hatchured and isolines of zero anomaly are drawn heavily. The crosses mark the positions of the TRANSPAC XBT drops. Increments are in .1°C (prepared by W. White, SIO).

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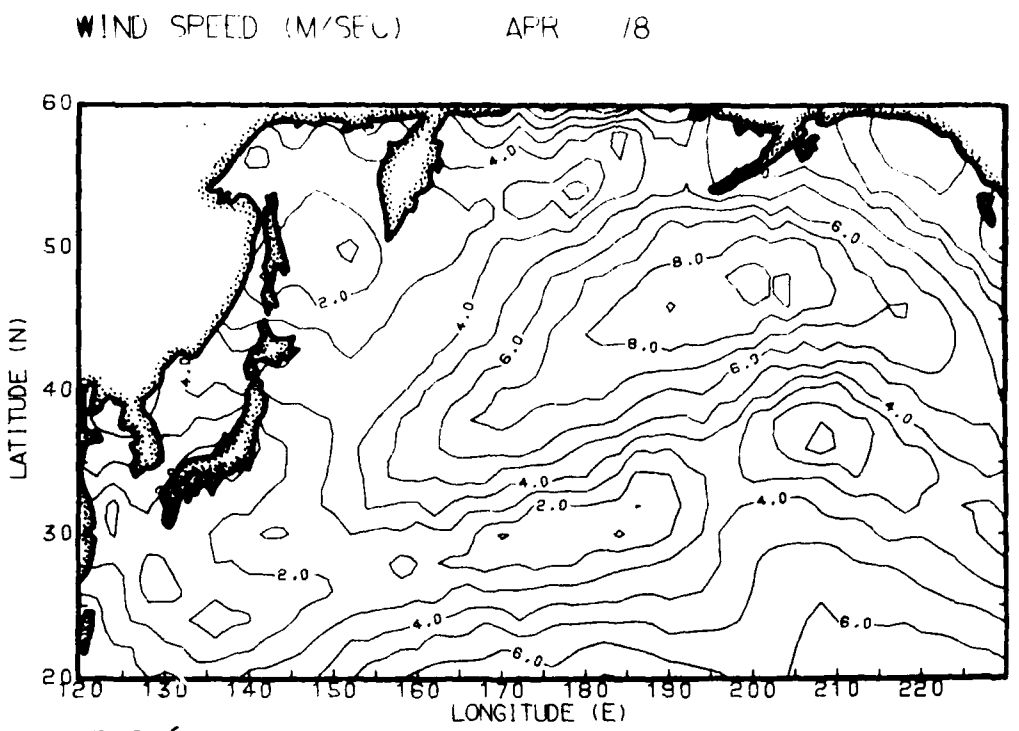



FIGURE 6.1 Absolute value of monthly mean vector wind velocities at 19.5 meters. Contour intervals are 1 m/sec.

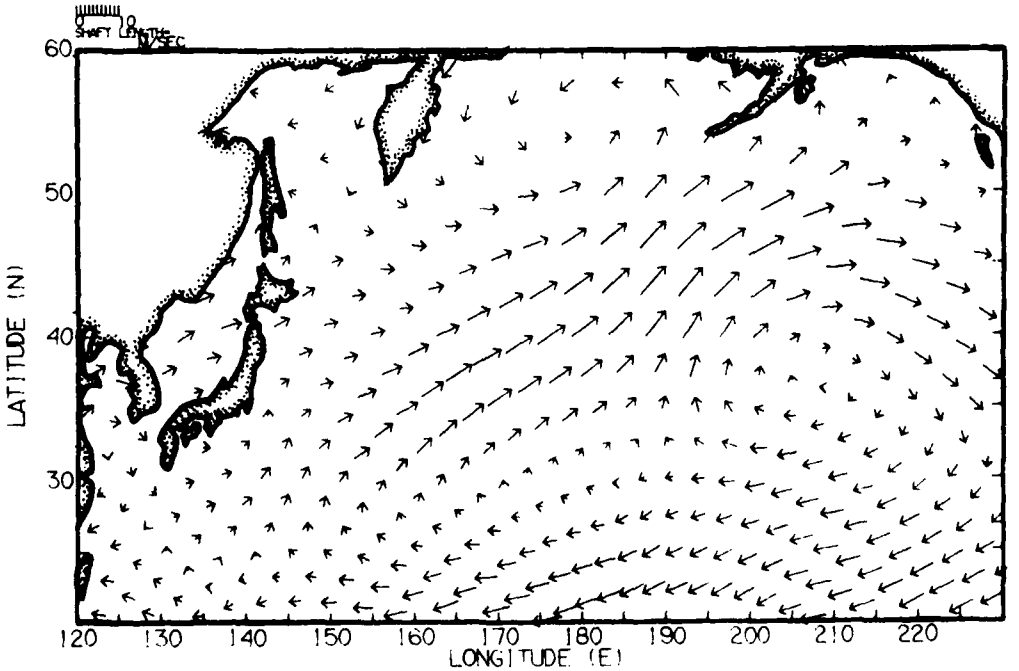



FIGURE 6.2 Direction arrows representing directions of monthly mean wind vectors at 19.5 meters. Length of arrow shaft indicates wind speed in m/sec. (See scale above figure).

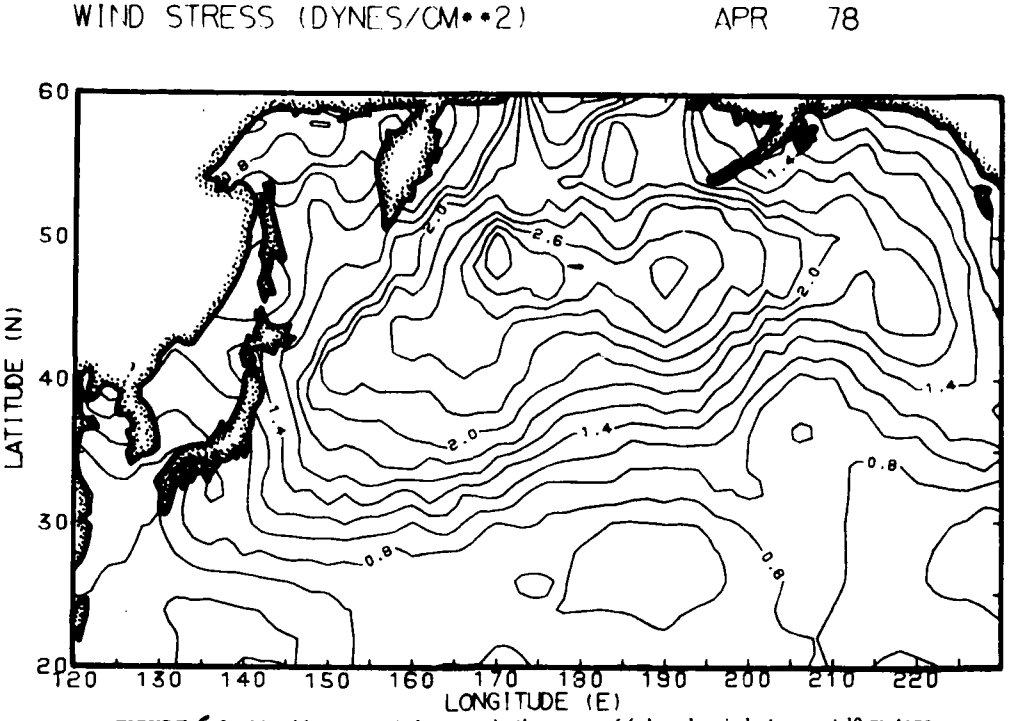
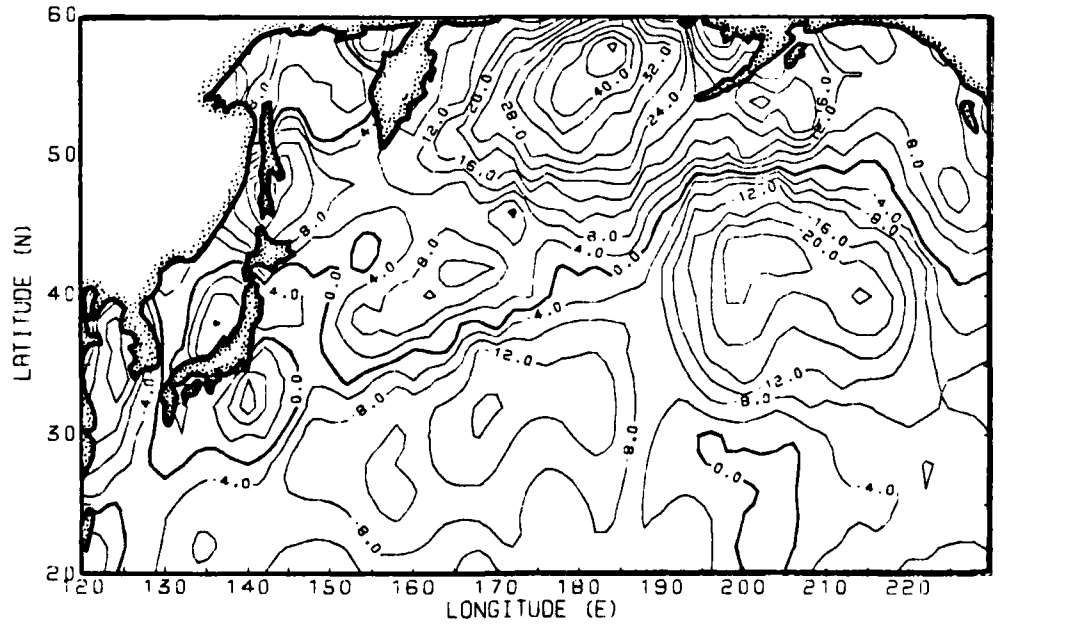



FIGURE 6.3 Monthly mean wind stress is the mean of 6-hourly wind stress at 10 meters calculated from FNWC wind data. Contour intervals are 0.2 dynes/cm$^2$.

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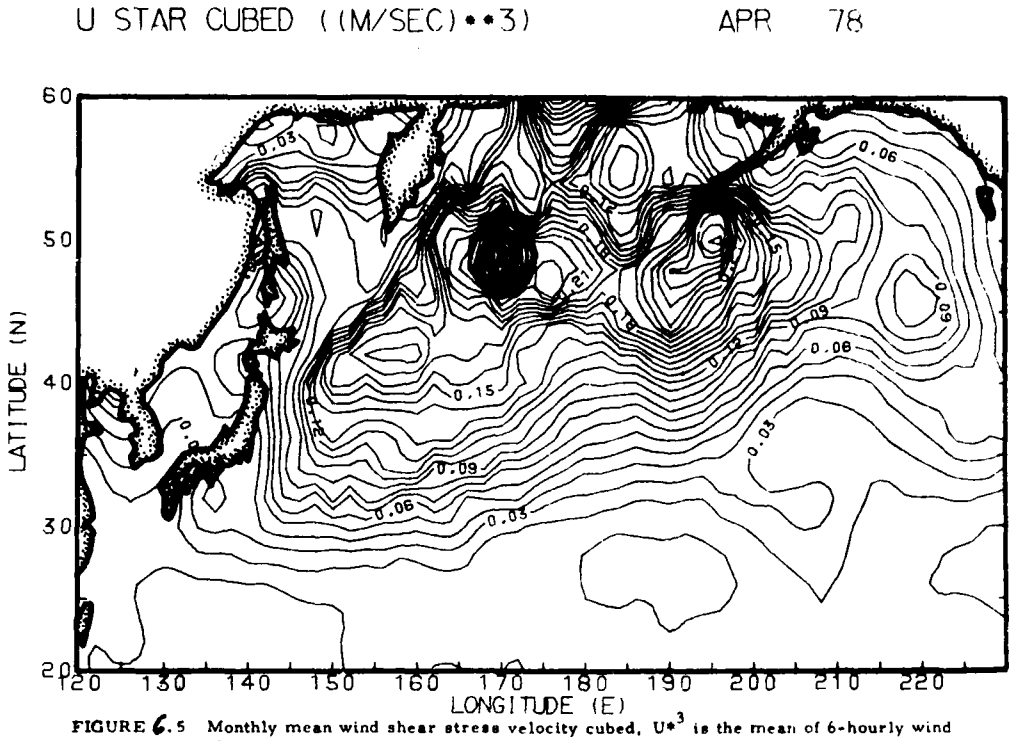



**FIGURE 6.5** Monthly mean wind shear stress velocity cubed, $U^{*3}$ is the mean of 6-hourly wind shear stress velocity cubed calculated from wind speed at 10 meters. Contour intervals are 0.02 $(m/sec)^3$.

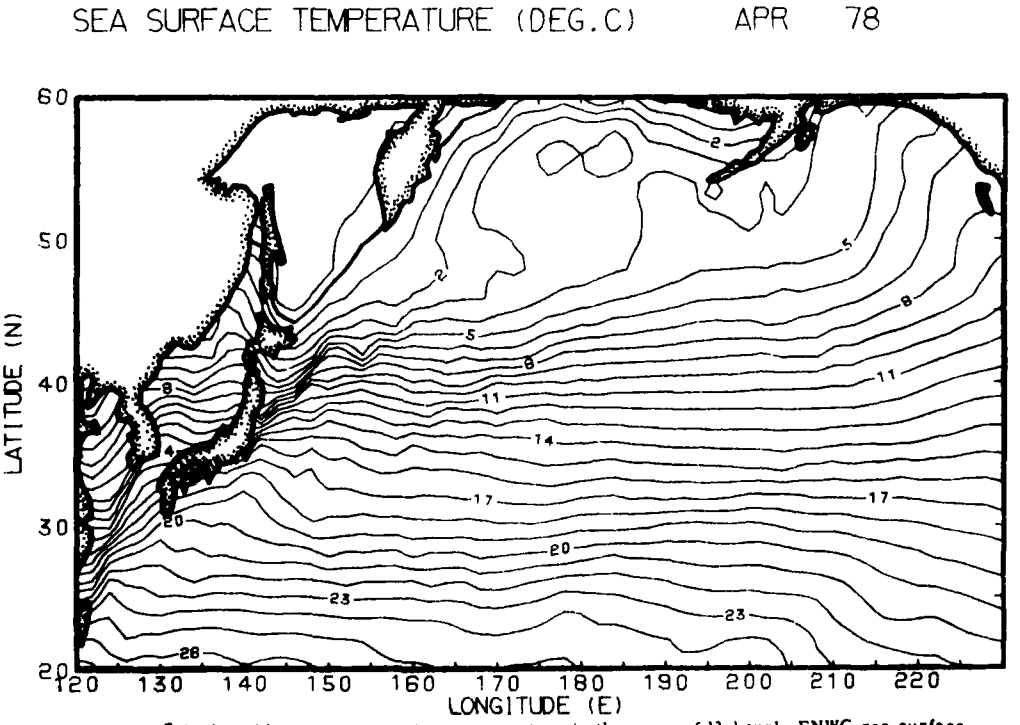



**FIGURE 6.6** Monthly mean sea surface temperature is the mean of 12-hourly FNWC sea surface temperatures. Contour intervals are 1°C.

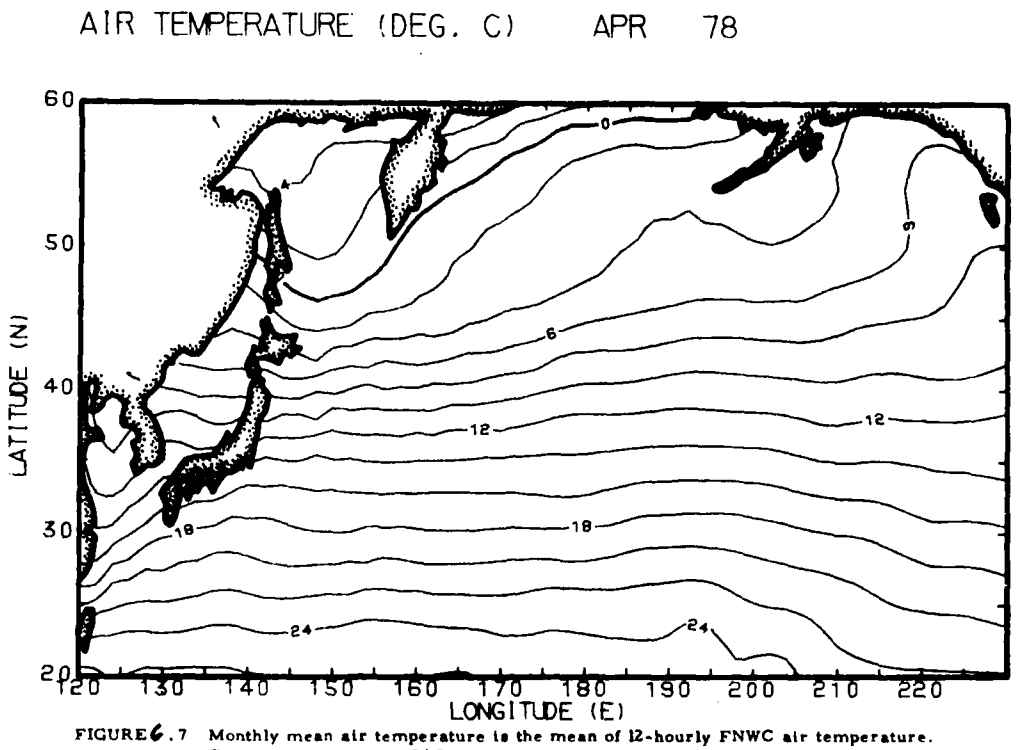
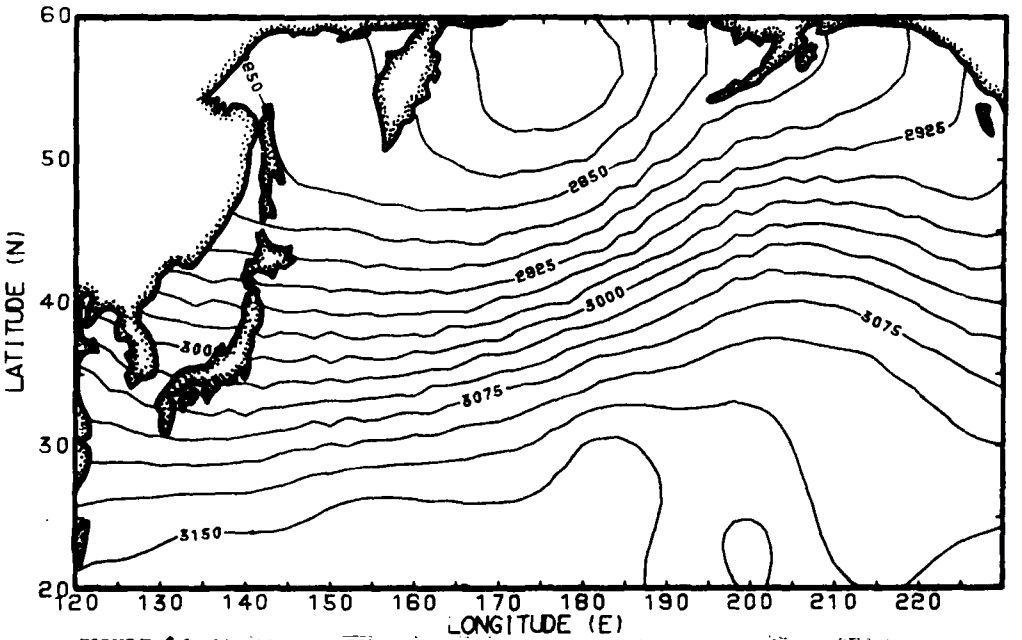



FIGURE 6.7 Monthly mean air temperature is the mean of 12-hourly FNWC air temperature. Contour intervals are 2°C.

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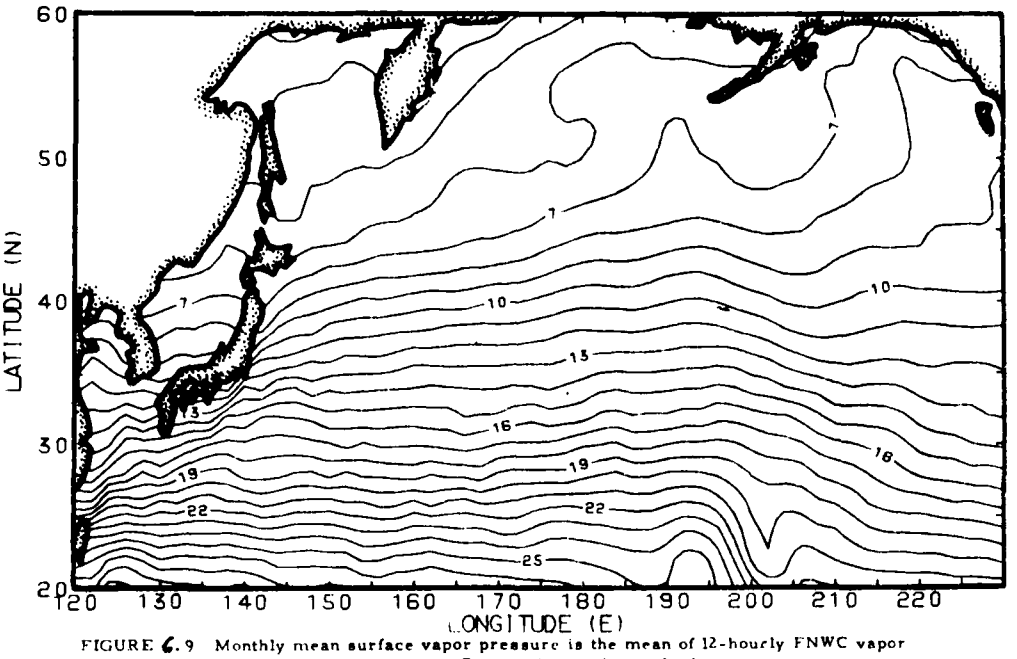
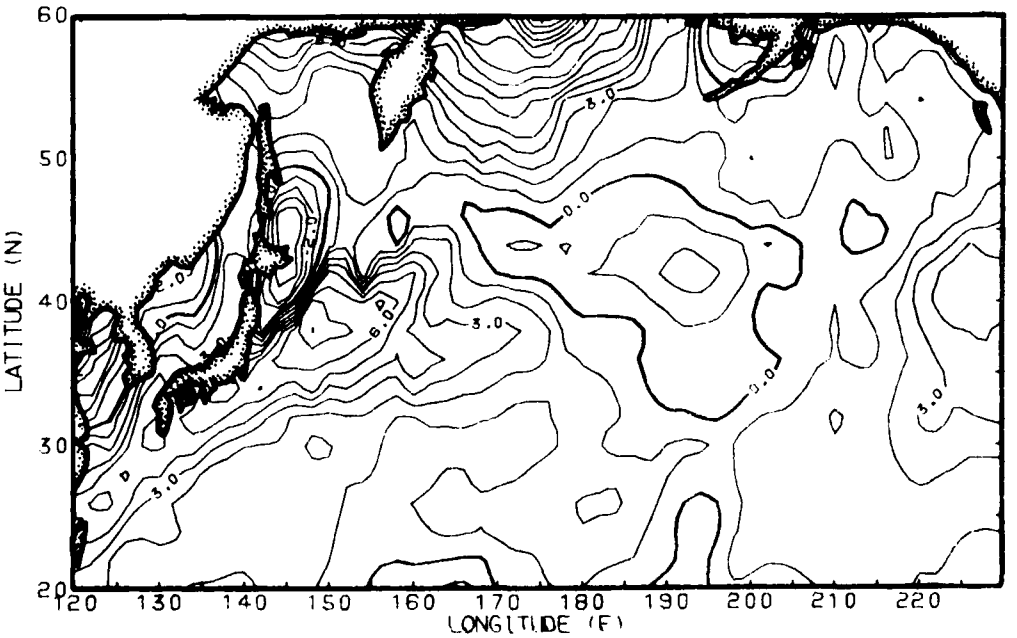



FIGURE 6.9 Monthly mean surface vapor pressure is the mean of 12-hourly FNWC vapor pressure at 19.5 meters. Contour intervals are 1 mb.

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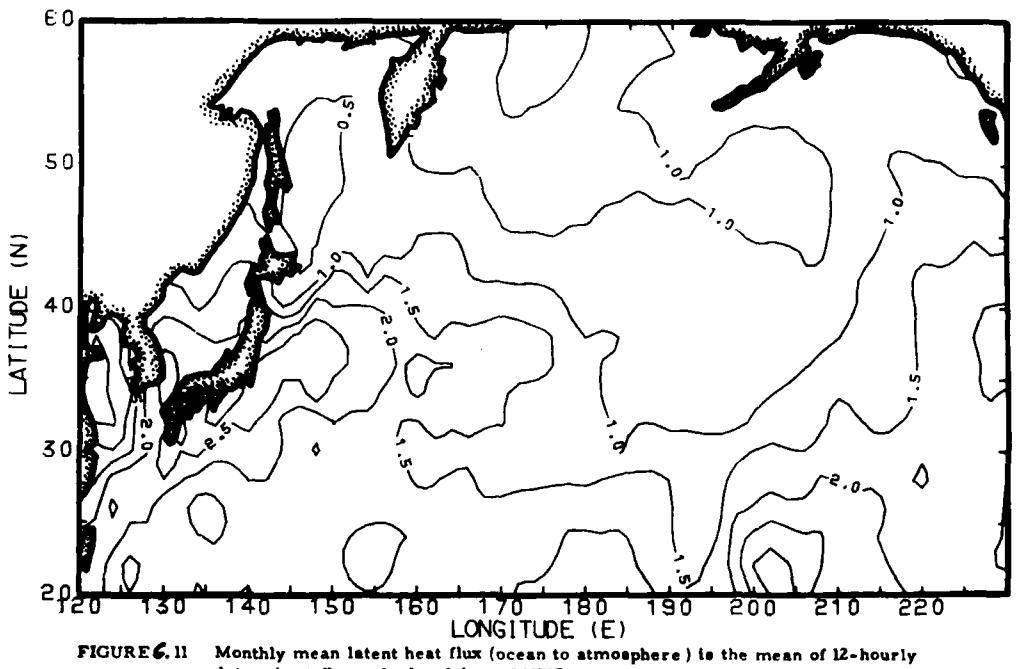
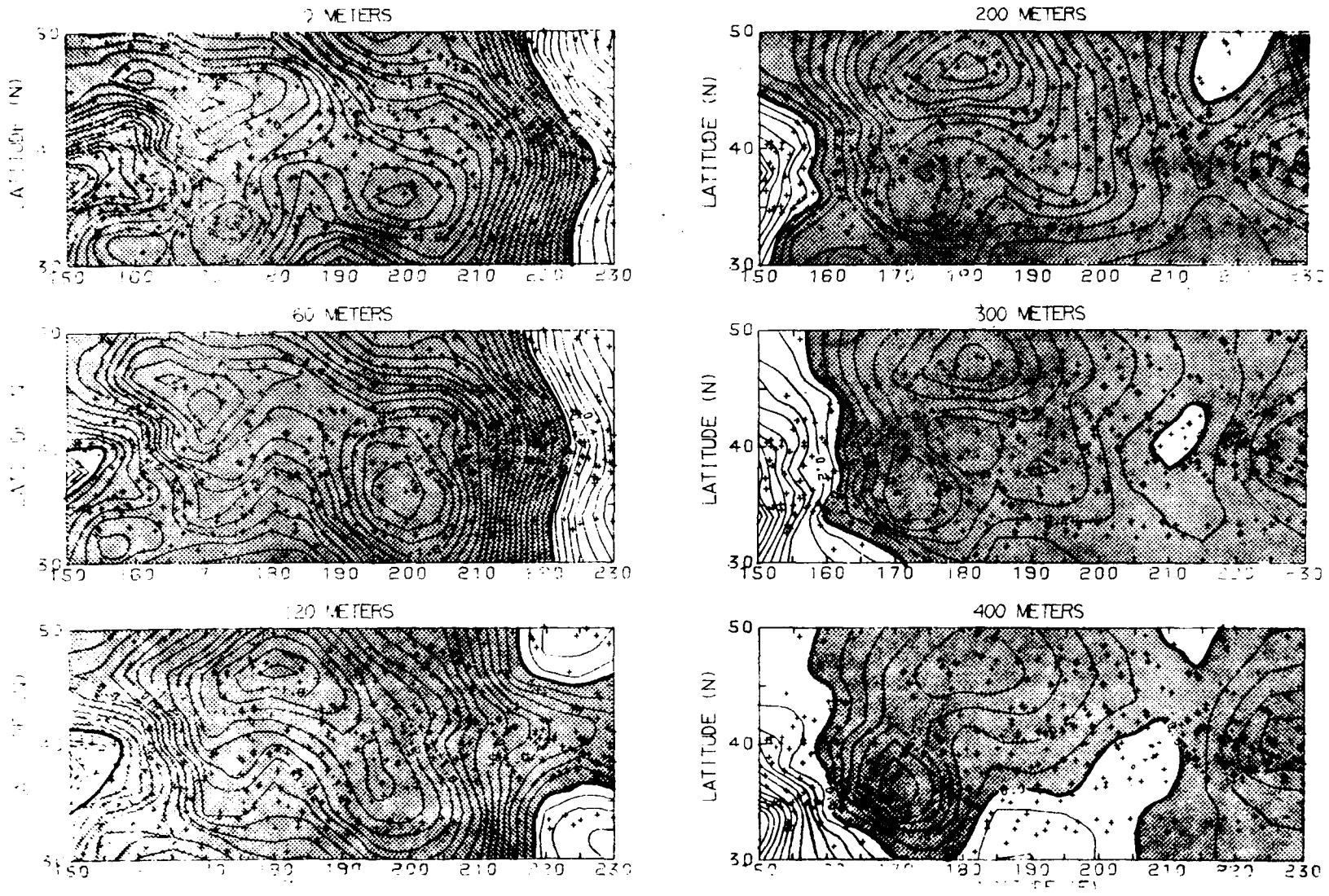



**FIGURE 6.11** Monthly mean latent heat flux (ocean to atmosphere) is the mean of 12-hourly latent heat flux calculated from FNWC sea temperature, vapor pressure and wind using a bulk formula. Isoline of zero heat flux are plotted heavily, and contour intervals are $0.5 \times 10^{-3}$ cal/cm$^2$ sec.

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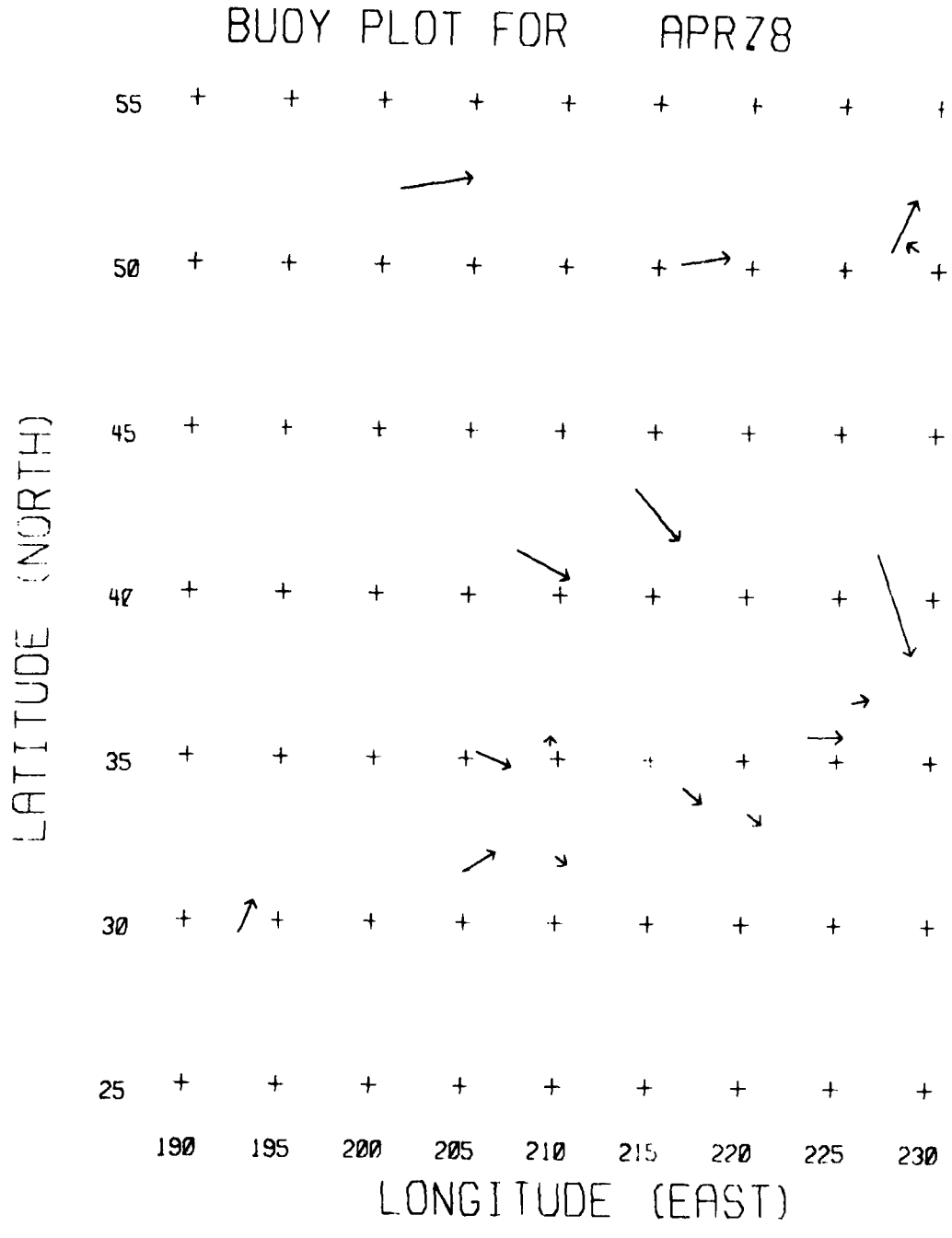


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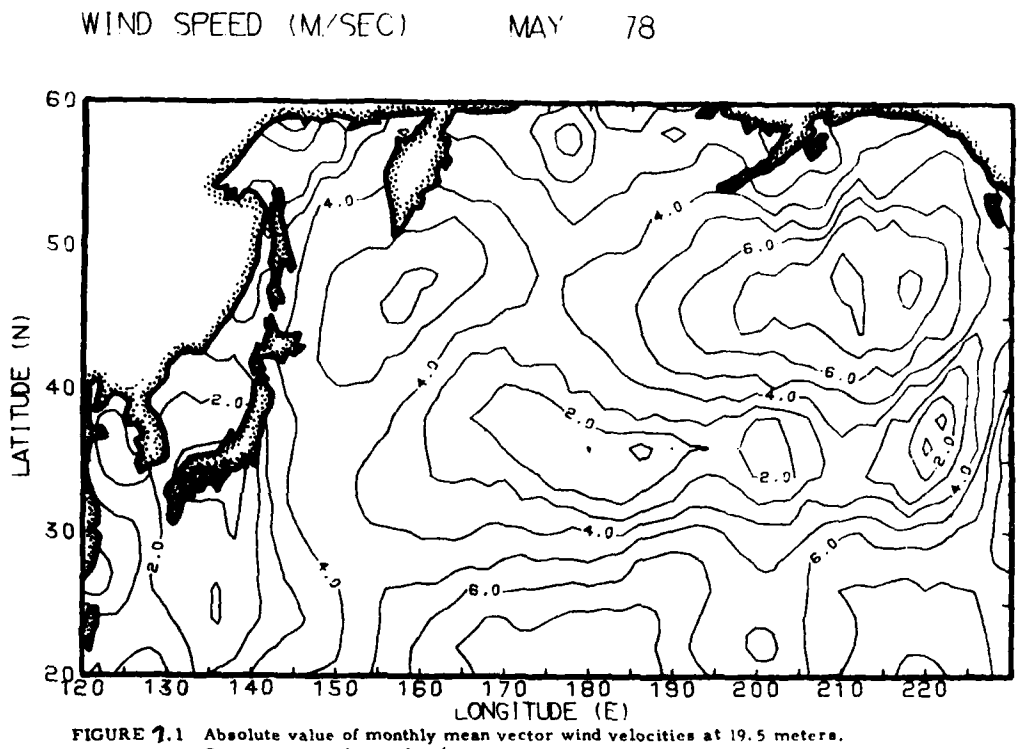


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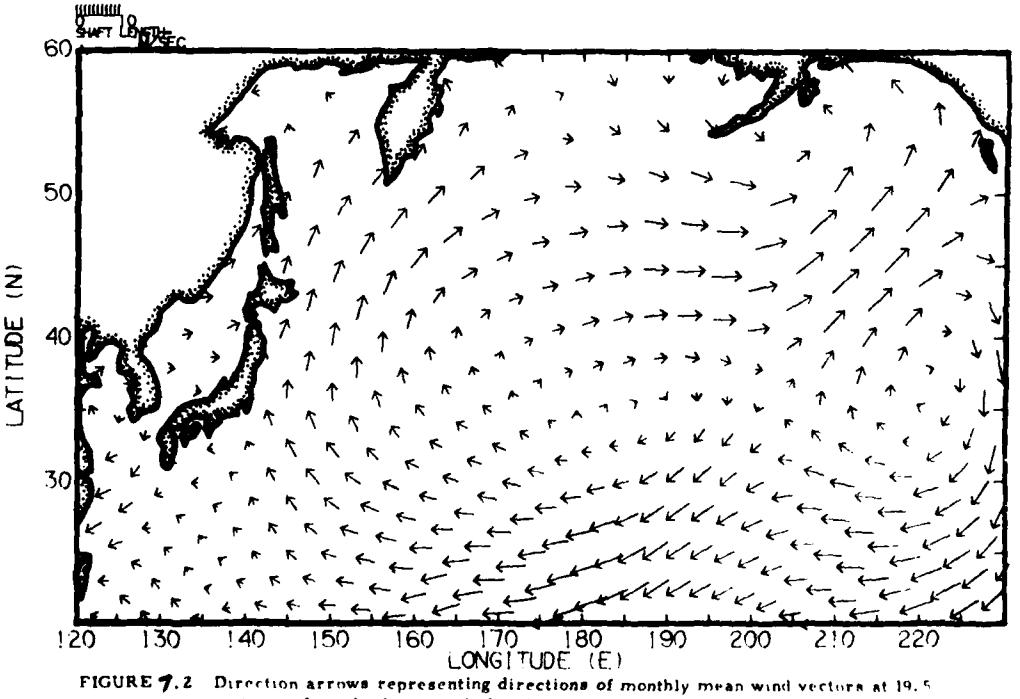


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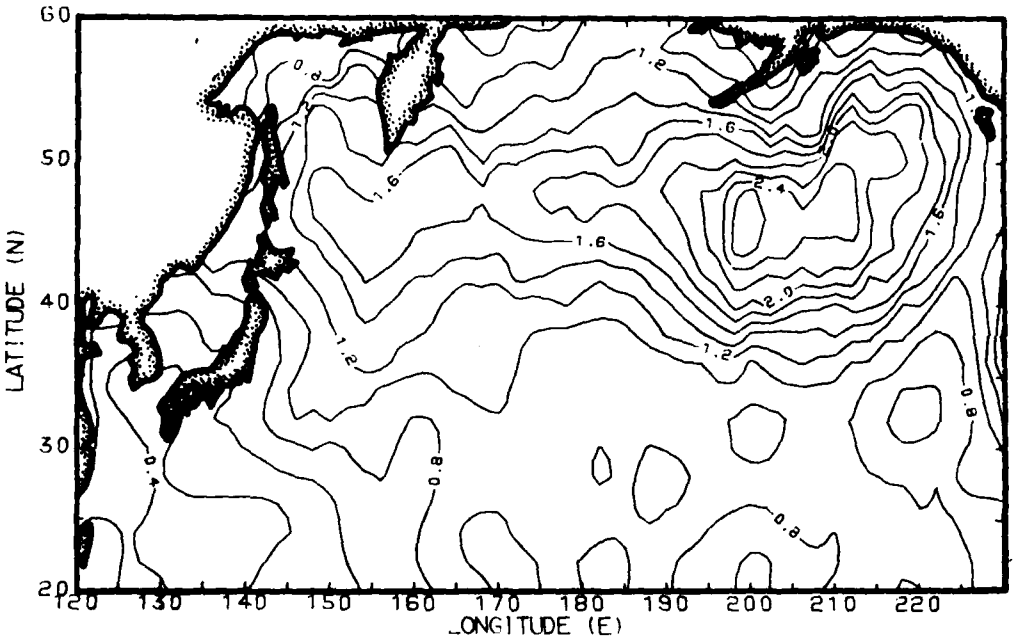
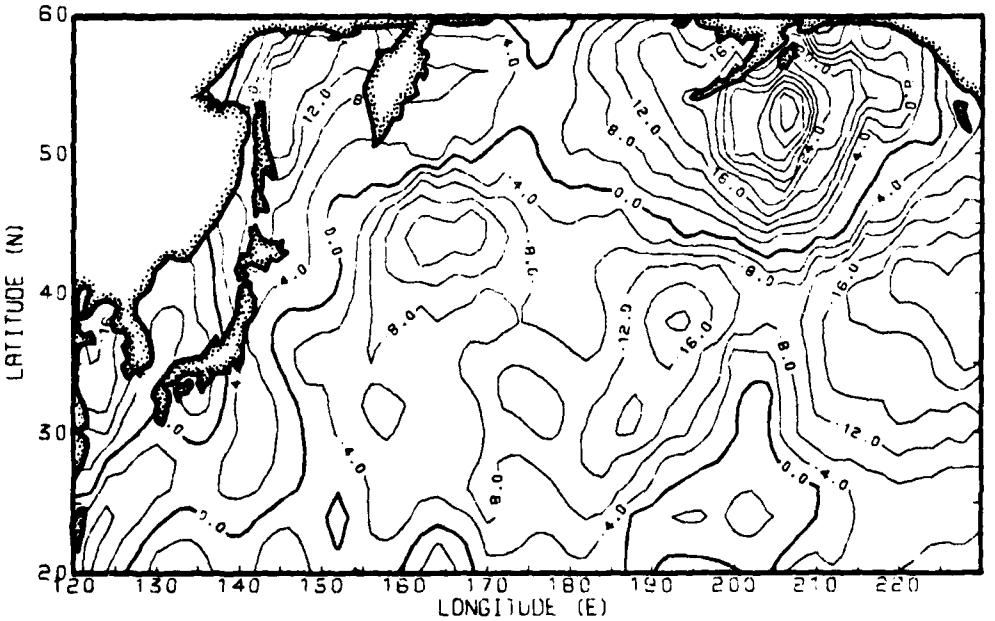



FIGURE 7.3 Monthly mean wind stress is the mean of 6-hourly wind stress at 10 meters calculated from FNWC wind data. Contour intervals are 0.2 dynes/cm$^2$.

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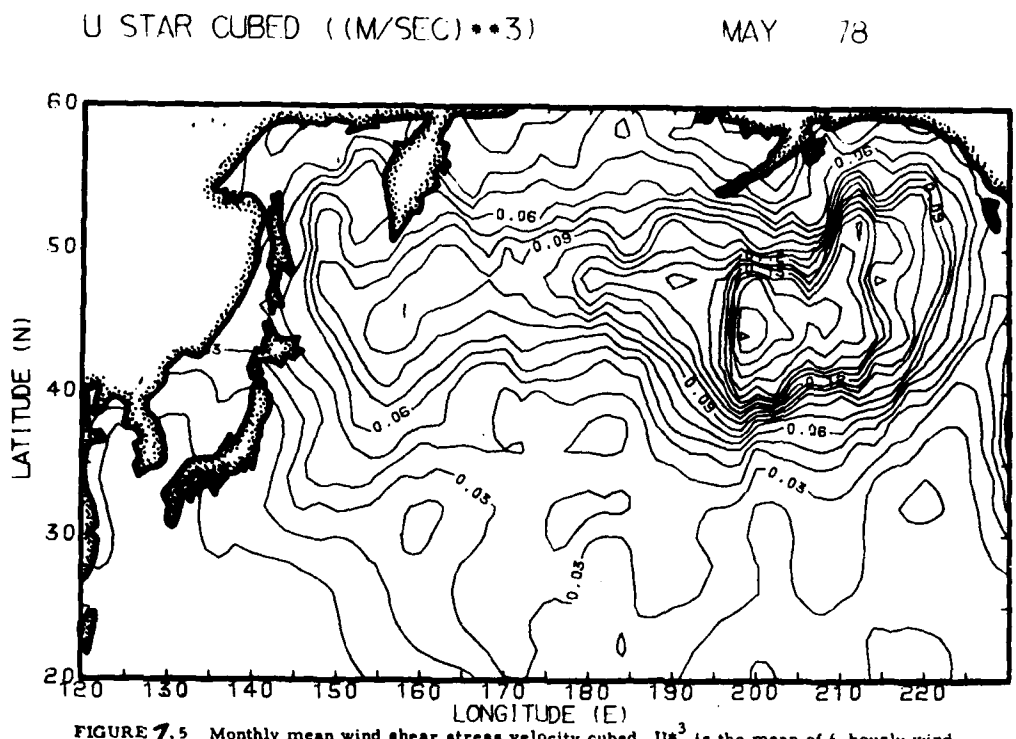


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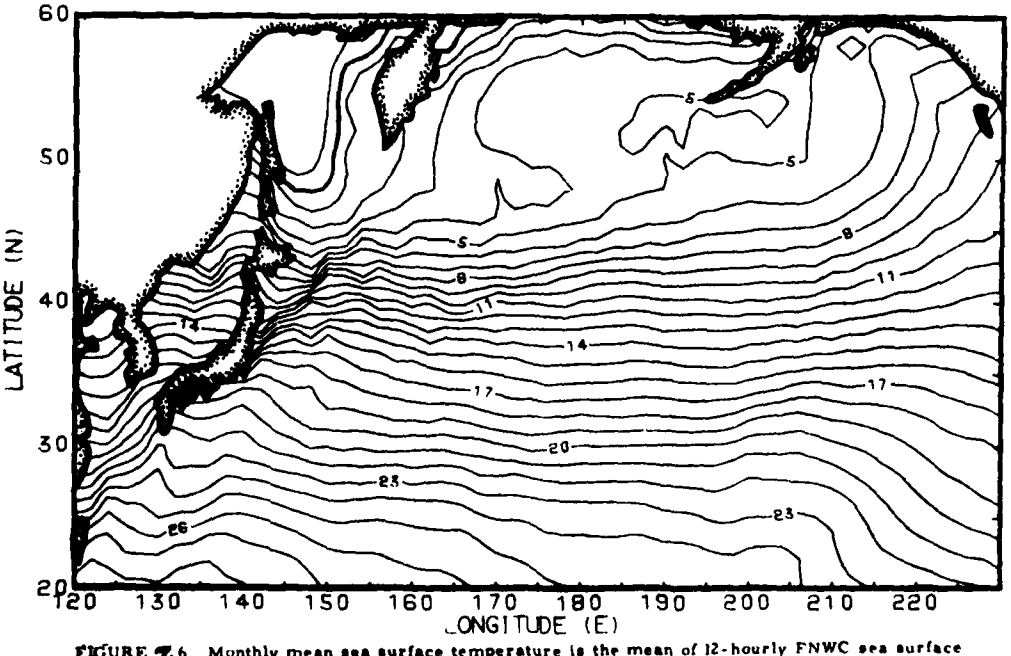



FIGURE 7.6 Monthly mean sea surface temperature is the mean of 12-hourly FNWC sea surface temperatures. Contour intervals are 1°C.

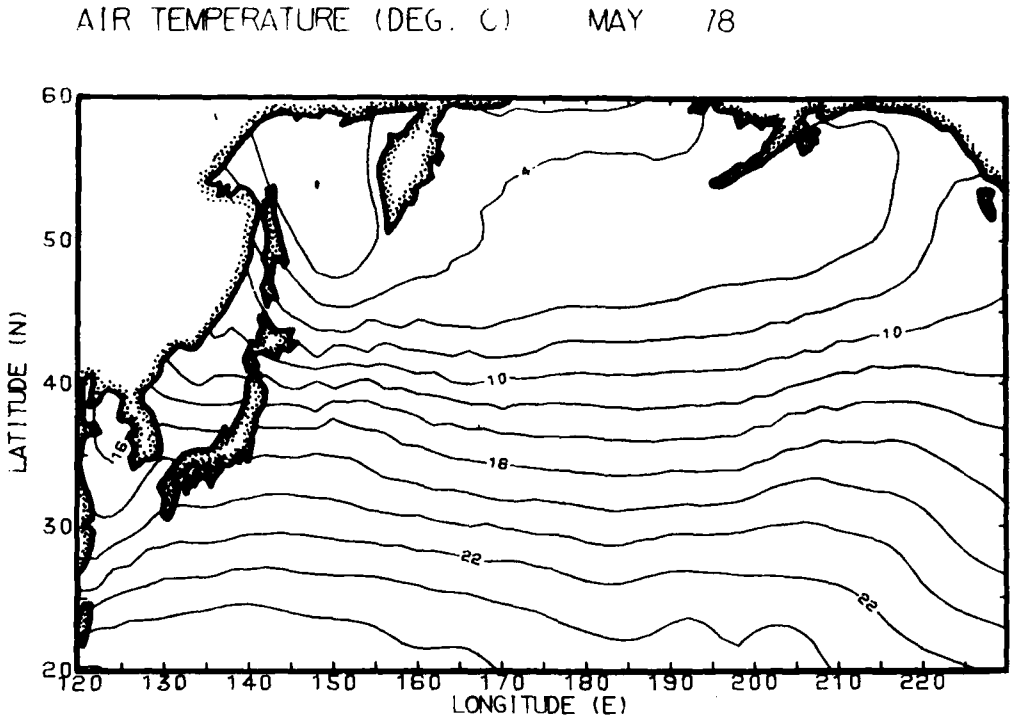
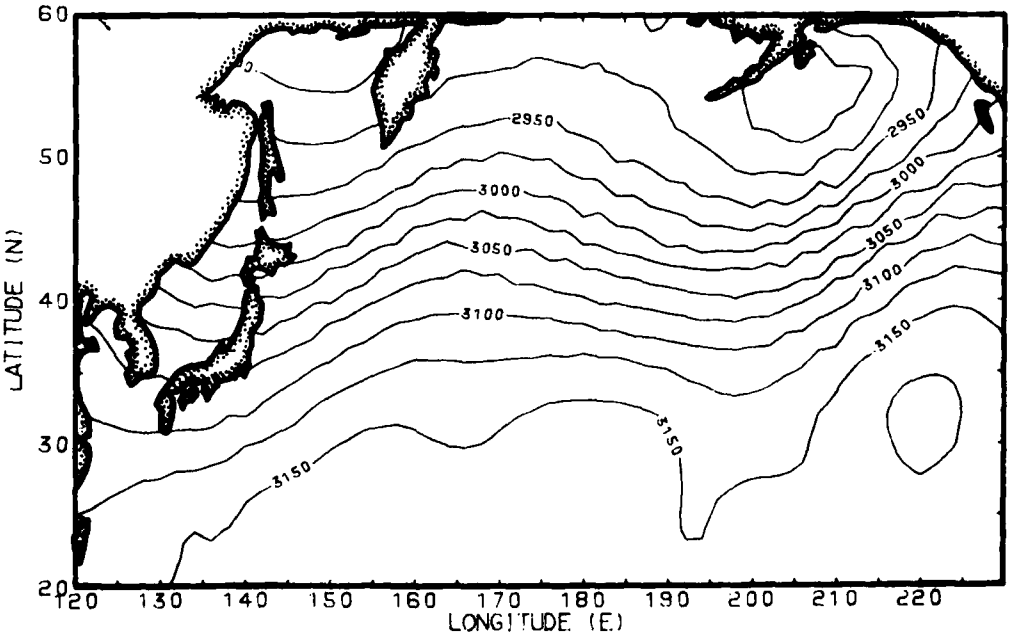



FIGURE 7.7 Monthly mean air temperature is the mean of 12-hourly FNWC air temperature. Contour intervals are 2°C.

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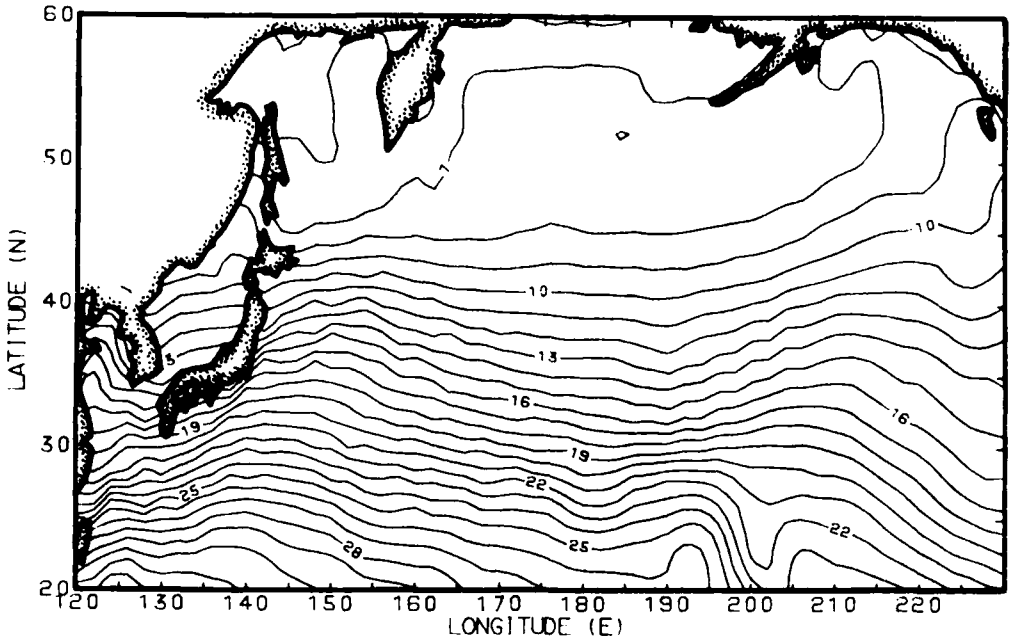


**FIGURE 7.9** Monthly mean surface vapor pressure is the mean of 12-hourly FNWC vapor pressure at 19.5 meters. Contour intervals are 1 mb.

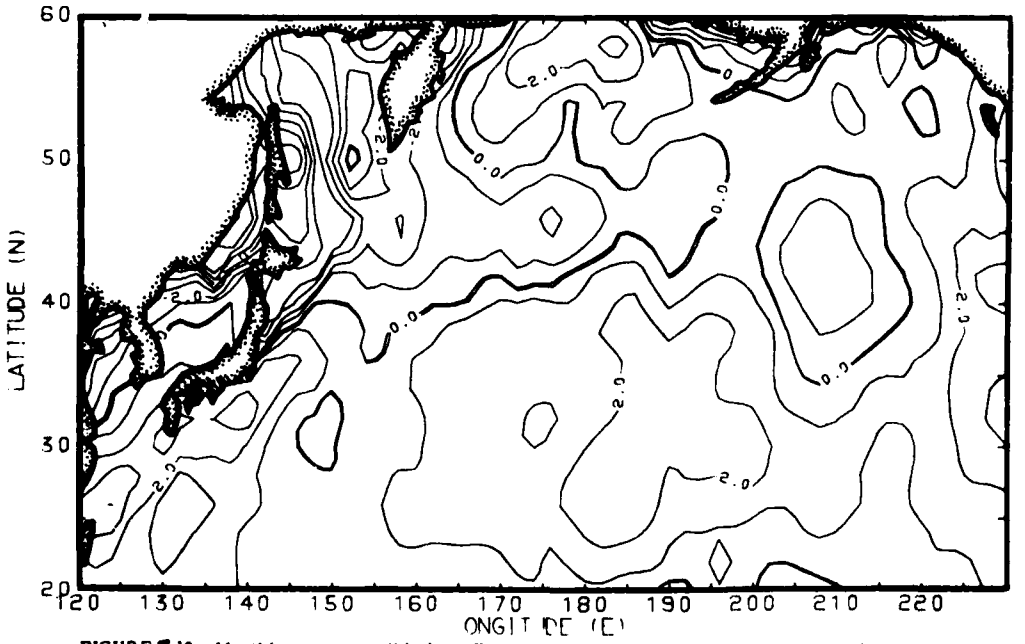


**FIGURE 7.10** Monthly mean sensible heat flux (ocean to atmosphere) is the mean of 12-hourly sensible heat flux calculated from FNWC air and sea temperature and wind using a bulk formula. Isolines of zero heat flux are plotted heavily, and contour intervals are $1.0 \times 10^{-4}$ cal/cm$^2$ sec.

FIGURE 7.11 Monthly mean latent heat flux (ocean to atmosphere) is the mean of 12-hourly latent heat flux calculated from FNWC sea temperature, vapor pressure and wind using a bulk formula. Isoline of zero heat flux are plotted heavily, and contour intervals are $0.5 \times 10^{-3}$ cal/cm$^2$ sec.

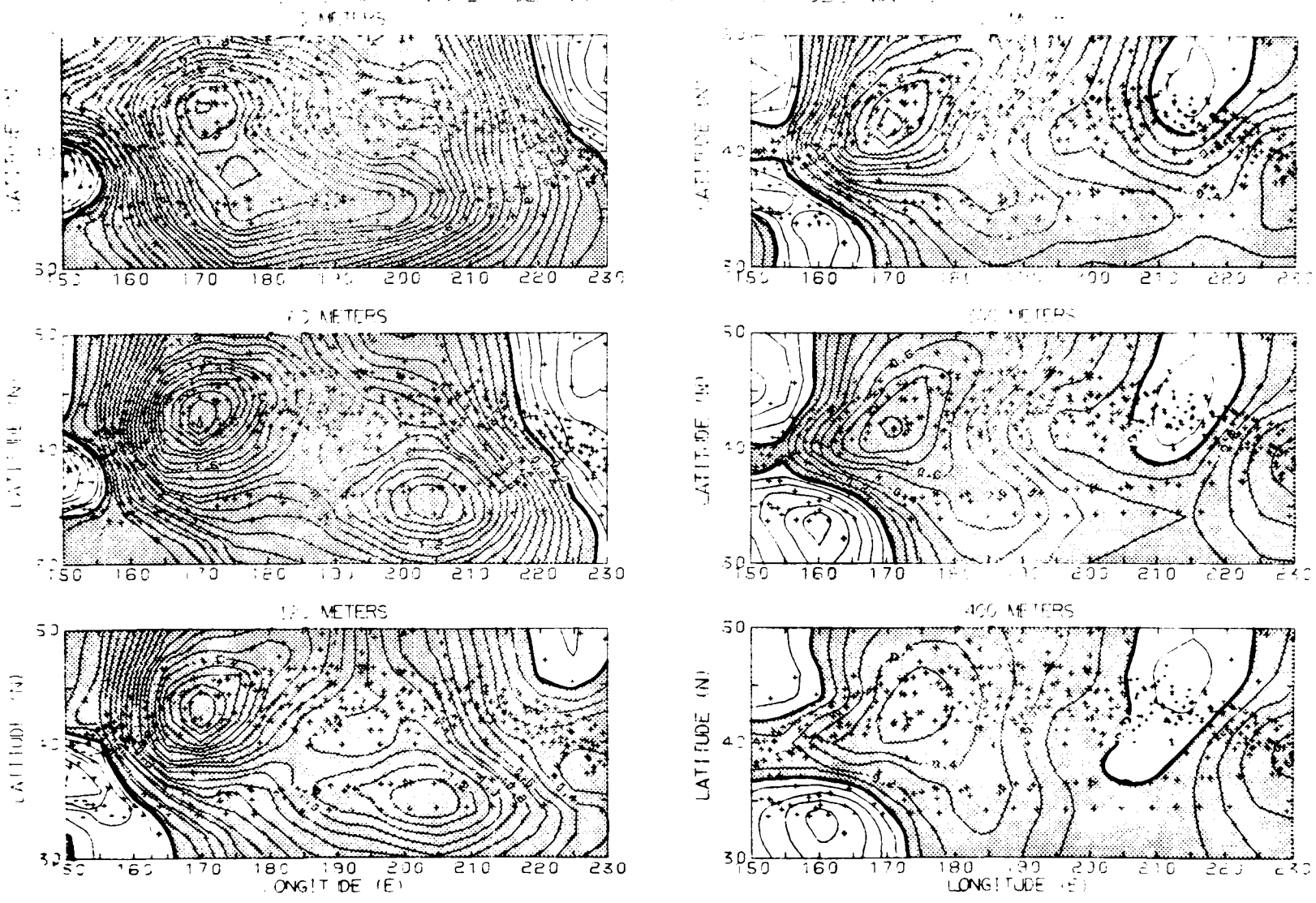


FIGURE 7.12 Monthly temperature anomalies (°C) contoured at fixed depths. Negative anomaly areas are hatchured and isoline of zero anomaly are drawn heavily. The crosses mark the positions of the TPANSPAC XBT drops. Increments are in .1°C (prepared by W. White, SIO).

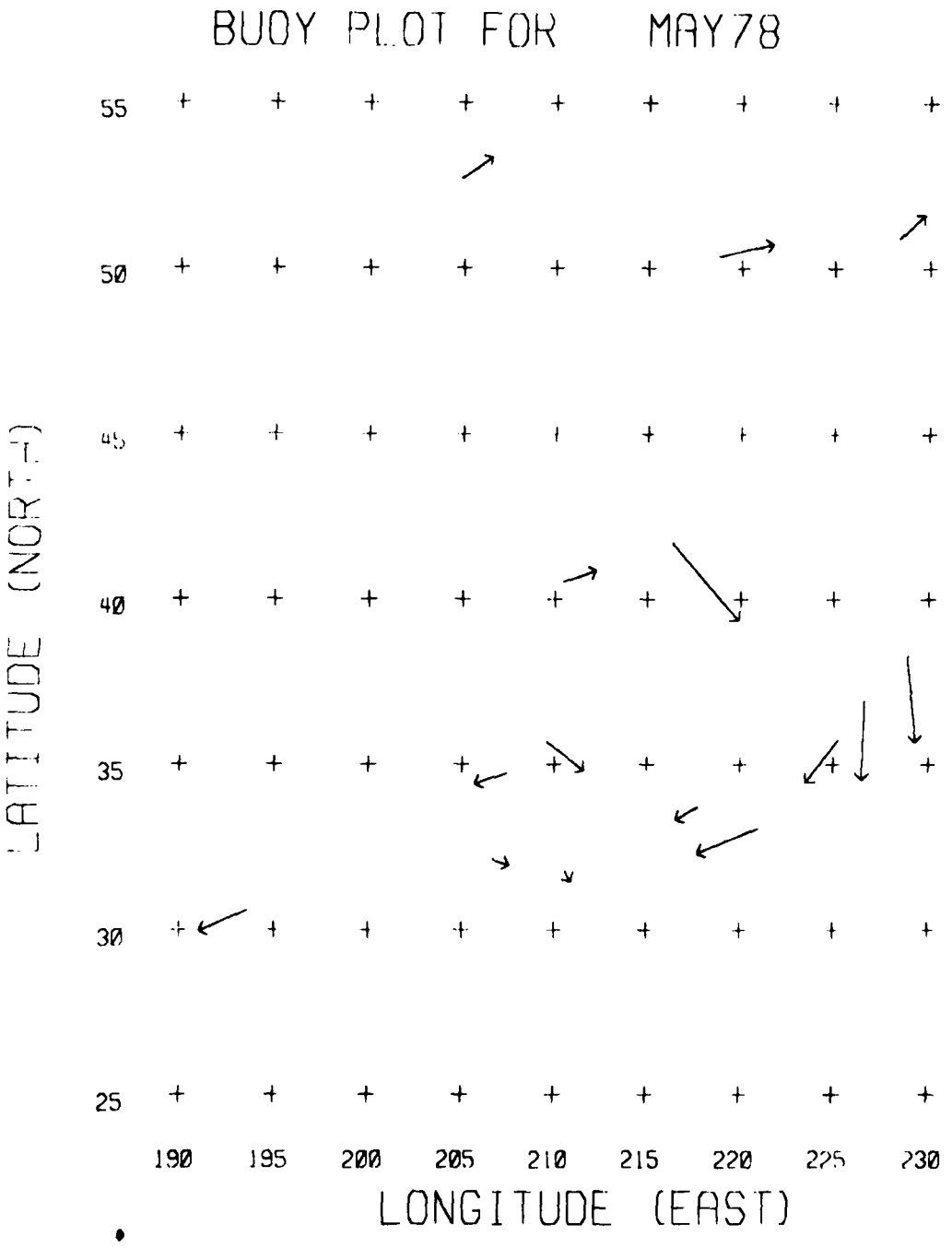


FIGURE 7.13 Monthly buoy tracks. Tracks are drawn from starting point at beginning of month to terminal point at end of month. Ratio of latitude to longitude is the same as in other figures.

## APPENDIX. Analysis Procedure

Since some revisions have been made in the calculation of curl of wind stress, and since it has been some time since the publication of ADS Report Number 1, which contained a complete outline of the analysis procedure, this appendix is included in this report.

FNOC data were taken from 63 x 63 polar gridded fields of 6-hourly wind speed and direction, and 12-hourly 700 mb height, sea surface temperature, air temperature, and vapor pressure. The wind at a ten meter height above sea level was estimated from FNOC 19.5 meter winds by an iterative scheme using the neutral flux-profile relationships obtained by Businger et al. (1971). Wind stress was calculated from FNOC wind speed and direction using a bulk aerodynamic equation:

$$\tau = -\rho\overline{uw} = \rho C_d U_{10}^2 \tag{A.1}$$

where

$\tau$ = *surface stress* $(dynes/cm^2)$

$\overline{uw}$ = *Reynolds stress,* $(m^2sec^{-2})$

$\rho$ = *air density* $= 1.2923\times10^{-3}$ $g/cm^3$

$U_{10}$ = *wind speed at 10 m* $(cm/sec)$

$C_d = 1.3\times10^{-3}$

The drag coefficient $C_d$ was found by Smith and Banke (1975) for $U_{10}$ = 10 m/sec. Vertical component of wind stress curl was calculated on the FNOC northern hemispheric grid using polar projection mapping and finite difference approximations.

The vertical component of wind stress curl is,

$$\hat{r}\cdot curl\vec{\tau} = \frac{1}{R\cdot\sin\theta}\cdot\left\{\frac{\partial(\tau_\phi\sin\theta)}{\partial\theta} - \frac{\partial\tau_\theta}{\partial\phi}\right\} \tag{A.2}$$

where $\theta$ and $\phi$ are co-latitude and east longitude in polar coordinates, respectively, and $\tau$ is wind stress, R is the Earth's radius, and $\hat{r}$ is a unit radius vector.

A finite differencing method will be used to estimate this equation. However, since the data resides on a polar stereographic grid, a finite differencing scheme must be expressed in terms of polar stereographic coordinates, and then related to co-latitude and longitude using

the chain rule. The finite differences are:

$$\partial\frac{\tau_\theta}{\partial\zeta} = \tau_\theta\Big|_{\zeta_{i-1}}^{\zeta_{i+1}}/(\zeta_{i+1}-\zeta_{i-1}) \tag{A.3}$$

$$= \tau_\theta\Big|_{\zeta_{i-1}}^{\zeta_{i+1}}/2\ ;\ i=1,63$$

$$\partial\frac{\tau_\theta}{\partial\eta} = \tau_\theta\Big|_{\eta_{j-1}}^{\eta_{j+1}}/(\eta_{j+1}-\eta_{j-1}) \tag{A.4}$$

$$= \tau_\theta\Big|_{\eta_{j-1}}^{\eta_{j+1}}/2;j=1,63$$

$$\frac{\partial(\tau_\phi\sin\zeta)}{\partial\zeta} = \tau_\phi\sin\theta\Big|_{\zeta_{i-1}}^{\zeta_{i+1}}/(\zeta_{i+1}-\zeta_{i-1}) \tag{A.5}$$

$$= \tau_\phi\sin\theta\Big|_{\zeta_{i-1}}^{\zeta_{i+1}}/2;i=1,63$$

$$\frac{\partial(\tau_\phi\sin\theta)}{\partial\eta} = \tau_\phi\sin\theta\Big|_{\eta_{j-1}}^{\eta_{j+1}}/(\eta_{j+1}-\eta_{j-1}) \tag{A.6}$$

$$= \tau_\phi\sin\theta\Big|_{\eta_{j-1}}^{\eta_{j+1}}/2;i=1,63$$

where $\zeta(\theta,\phi)$ and $\eta(\theta,\phi)$ are the abscissa and ordinate grid axes of the 63 × 63 polar stereographic grid.

The partial derivatives may be calculated for the polar stereographic mapping equations:

$$\zeta = 32+31.205\left\{\frac{1-\cos\theta}{1+\cos\theta}\right\}^{1/2}\cdot\sin(\phi+80);\ i=1,63, \tag{A.7}$$

$$\eta = 32-31.205\left\{\frac{1-\cos\theta}{1+\cos\theta}\right\}^{1/2}\cdot\cos(\phi+80);\ j=1,63, \tag{A.8}$$

and the partial derivatives of $\zeta$ and $\eta$ with respect to $\theta$ and $\phi$ are:

$$\frac{\partial\zeta}{\partial\phi} = 31.205\left\{\frac{1-\cos\theta}{1+\cos\theta}\right\}^{1/2}\cdot\cos(\phi+80) \tag{A.9}$$

$$\frac{\partial\eta}{\partial\phi} = 31.205\left\{\frac{1-\cos\theta}{1+\cos\theta}\right\}^{1/2}\cdot\sin(\phi+80) \tag{A.10}$$

$$\frac{\partial\zeta}{\partial\theta} = 31.205\left\{\frac{1-\cos\theta}{1+\cos\theta}\right\}^{-1/2}\cdot\frac{\sin\theta}{(1+\cos\theta)^2}\sin(\phi+80) \tag{A.11}$$

$$\frac{\partial\eta}{\partial\theta} = -31.205\left\{\frac{1-\cos\theta}{1+\cos\theta}\right\}^{-1/2}\cdot\frac{\sin\theta}{(1+\cos\theta)^2}\cos(\phi+80) \tag{A.12}$$

The vertical component of the wind stress curl can then be estimated, using equations A.2 through A.12, as:

$$\hat{r}\cdot curl\vec{\tau} = \frac{15.6025}{R\sin\theta_{ij}}\left\{\frac{1-\cos\theta_{ij}}{1+\cos\theta_{ij}}\right\}^{1/2}\cdot\left[\tau_\phi\sin\theta\Big|_{\zeta_{i-1}}^{\zeta_{i+1}}\frac{\sin(\phi+80)}{\sin\theta}\Big|_{i,j}\right. \tag{A.13}$$

$$-\tau_\phi\sin\theta\Big|_{\eta_{j-1}}^{\eta_{j+1}}\frac{\cos(\phi+80)}{\sin\theta}\Big|_{i,j}$$

$$\left.-\tau_\theta\Big|_{\zeta_{i-1}}^{\zeta_{i+1}}\cos(\phi+80)\Big|_{i,j}-\tau_\theta\Big|_{\eta_{j-1}}^{\eta_{j+1}}\sin(\phi+80)\Big|_{i,j}\right]$$

Sensible heat flux ($cal/cm^2sec$) was obtained using an empirical bulk formula (Friehe and Schmitt, 1976):

$$S.H.F. = \rho C_p[0.2+C_h \cdot U_{10} \cdot (T_s - T_a)] \tag{A.14}$$

where

$C_p = 0.24\ cal/gm°C$

$C_h = 0.91\times10^{-3}$

$T_s$ = *sea surface temperature*

$T_a$ = (10 *meter*) *air temperature*

The latent heat flux ($cal/cm^2sec$) was also calculated from a bulk formula (Friehe and Schmitt, 1976):

$$L.H.F. = L \cdot C_e \cdot U_{10} \cdot [Q_{sea} - Q] \tag{A.15}$$

where

$L = 595\ cal/gm$ (*heat of evaporation*)

$C_e = 1.32\times10^{-3}$

$Q = 0.75 \cdot [EAIR\ (gm \cdot m^{-3}) \equiv FNOC\ vapor\ pressure]$

$Q_{sea} = 1.667\times10^{-7} \cdot [e^{17.19 \cdot [(T_s+273)/273]}]$.

Stress, stress-curl and $U^3$ fields were calculated at 00z, 06z, 12z ; heat fluxes were calculated for 00z and 12z every day. These calculated fields were then averaged to obtain daily, 5-daily, and monthly vector means of wind speed and direction. Monthly means were contoured over the region of the North Pacific from 120E to 230E and 20N to 60N.

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